Hydrogeomorphic Evaluation of Ecosystem Restoration Options For The

Missouri River Floodplain

From River Mile (RM) 670 South of Decatur, Nebraska to RM 0 at St. Louis, Missouri

Prepared For:

U. S. Fish and Wildlife Service
Region 3
Minneapolis, Minnesota

Greenbrier Wetland Services
Report 15-02

Mickey E. Heitmeyer
Joseph L. Bartletti
Josh D. Eash

December 2015

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U. S. Fish and Wildlife Service Region 3
Refuges and Wildlife
Minneapolis, Minnesota

By:

Mickey E. Heitmeyer
Greenbrier Wetland Services
Advance, MO 63730

Joseph L. Bartletti
Prairie Engineers of Illinois, P.C.
Springfield, IL 62703

And

Josh D. Eash
U.S. Fish and Wildlife Service, Region 3
Water Resources Branch
Bloomington, MN 55437

Greenbrier Wetland Services
Report No. 15-02

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Mickey E. Heitmeyer, PhD
Greenbrier Wetland Services
Route 2, Box 2735
Advance, MO 63730
www.GreenbrierWetland.com

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EXECUTIVE SUMMARY

Karen Kyle

This report provides a hydrogeomorphic (HGM) evaluation of ecosystem restoration options for the Lower Missouri River (LMR) floodplain from River Mile (RM) 670 south of Decatur, Nebraska to RM 0 at St. Louis, Missouri. This LMR floodplain covers 680 river miles and about 1.5 million acres. While currently free-flowing, the LMR today is highly regulated by upstream reservoirs and water-control protocols and the river channel is greatly restricted and altered in a channelized form. Most of the large river tributaries in the LMR also have greatly altered land and water uses in their watershed, river channels, and floodplains. Currently, many state and federal agencies, private conservation groups, and other entities are directing efforts to restore and enhance destroyed and degraded habitats in the LMR and its major tributaries. Clearly, a major challenge for the future conservation of this valuable ecosystem is to protect, restore, enhance, and manage critical parts of the historic LMR given the constraints of altered ecological landform, processes, and communities.

This report has three objectives:

1. Identify the pre-European settlement (late 1700s to early 1800s) ecosystem attributes and ecological processes in the LMR.
2. Evaluate differences between the presettlement and current conditions in the LMR with specific reference to alterations in hydrology, community structure and distribution, and resource availability to key fish and wildlife species.
3. Identify restoration and management for potential floodplain community restoration and ecological attributes needed to successfully restore specific habitats and conditions within the LMR.

Report information is provided for six primary ecoregions, or river valley segments. These include: 1) RM 0 to RM 130 (hereafter referred to as the Osage Reach), 2) RM 131 to RM 250 (Grand Reach), 3) RM 251 to RM 367 (Kansas Reach), 4) RM 368 to RM 463 (Nodaway Reach), 5) RM 464 to RM 595 (Platte Reach), and 6) RM 596 to RM 680 (Little Sioux Reach). The division of the LMR into these six reaches separates the study area into areas between substantive tributaries that have relatively uniform physiographic and geological characteristics and somewhat similar lengths. All of the selected tributaries that represent LMR separation points add greater than approximately five percent of the cumulative drainage area and/or drains an area of hydrogeomorphologically different hydrologic responses, sediment yields, or water-quality contributions. Maps of HGM attributes covered in this study are presented in 13 panels, each about 40 miles long, which cover the six reaches.

The HGM approach used in this study obtained and evaluated historical and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrological regimes, 5) plant and animal communities, and 6) physical anthropogenic features of landscapes in the LMR. An important part of the HGM approach was the development of a matrix of understanding, and prediction, of potential historical vegetation communities (referred to as PNV) using scientific data discovery and field validation using published literature (such as General Land Office survey notes and maps), vegetation community reference sites, and state-of-the-art understanding of plant species relationships to system attributes. Geospatial maps of all HGM data used in the report are provided in the Map Set Appendix to this report.

Major community/habitat types that historically were present in the LMR included: 1) the main river channels and islands/bars of the Missouri River and major tributaries; 2) river chutes and side channels; 3) abandoned channel bottomland lakes (oxbows and sloughs); 4) riverfront, floodplain, and slope forests; 5) mesic, wet-mesic, bottomland, and wet prairies (including wet prairie marshes); and woodland-prairie savanna. Descriptions of these community types and relationships with HGM attributes are provided in the report. For floodplain habitats, bottomland lakes with variable wetland

and aquatic vegetation/open water occur in different age, mostly less than 2,000 years old) abandoned river channels and sloughs. While present in all river reaches, bottomland lakes are especially common in the Missouri-Mississippi River Confluence area, the Nodaway Reach, the Platte Reach, and the Little Sioux Reach. Linear bands of riverfront forest historically (and currently) occurred along the Missouri River channel throughout the LMR, with especially large composition of the Osage, Grand, and Nodaway Reaches. Floodplain forest also was present throughout the LMR with large components interspersed with riverfront forest in the Osage and Grand Reaches, larger contiguous tracts in the western Kansas Reach, and higher elevation areas near the river channel north of St. Joseph, Missouri. Slope forest occupied alluvial fans and colluvial slopes along floodplain edges where upland bluffs and hills merged with the lower elevation floodplain. Slope forest was especially marked along the loess bluffs of northwest Missouri and southwest Iowa. Prairie complexes in the LMR were most abundant in the Missouri-Mississippi River Confluence area, the eastern Kansas Reach, and north of St. Joseph. Northern reaches included some upland mesic prairie on higher elevation edges of the floodplain. Wetter bottomland prairie and marsh communities were scattered throughout the LMR adjacent to or in bottomland lakes and low elevation floodplain sumps and depressions where fine sediment clays were deposited. Savanna communities historically were present in the LMR in rather small, narrow, bands along edges of larger prairie tracts.

Many past studies and contemporary photographs and maps have documented the extensive changes to the LMR ecosystem. This report generally describes and references these alterations and past studies about landform, hydrology, and vegetation communities to understand how presettlement community distribution and extent have changed and to identify options and potential opportunities for restoration. Many resource conservation initiatives and plans seek to restore habitats in the LMR including specific objectives to reestablish native terrestrial and wetland plant communities along the Missouri River channel and its floodplain. This HGM report provides information specifically focused on identifying options, and certain subsequent management needs, to restore floodplain communities, which embodies the above landscape-scale ecosystem restoration objective.

Based on information gathered in this HGM study, the following conservation actions are recommended in the LMR:

1. Protect and sustain existing floodplain areas that have plant communities similar to presettlement conditions.
2. Restore plant and animal communities in appropriate topographic and geomorphic landscape position.
3. Restore at least some sustainable “patches” of habitats that have been highly destroyed or degraded.
4. Restore habitats and areas that can serve as a “core” of critical, sometimes limiting, resources that can complement and encourage restoration and management on adjacent and regional private lands.

Specific ecosystem restoration option recommendations are provided for each LMR river reach. These recommendations are based largely on PNV maps produced from HGM matrix evaluation. Also, the HGM report suggests considerations for a landscape vision for the LMR that contains the following points:

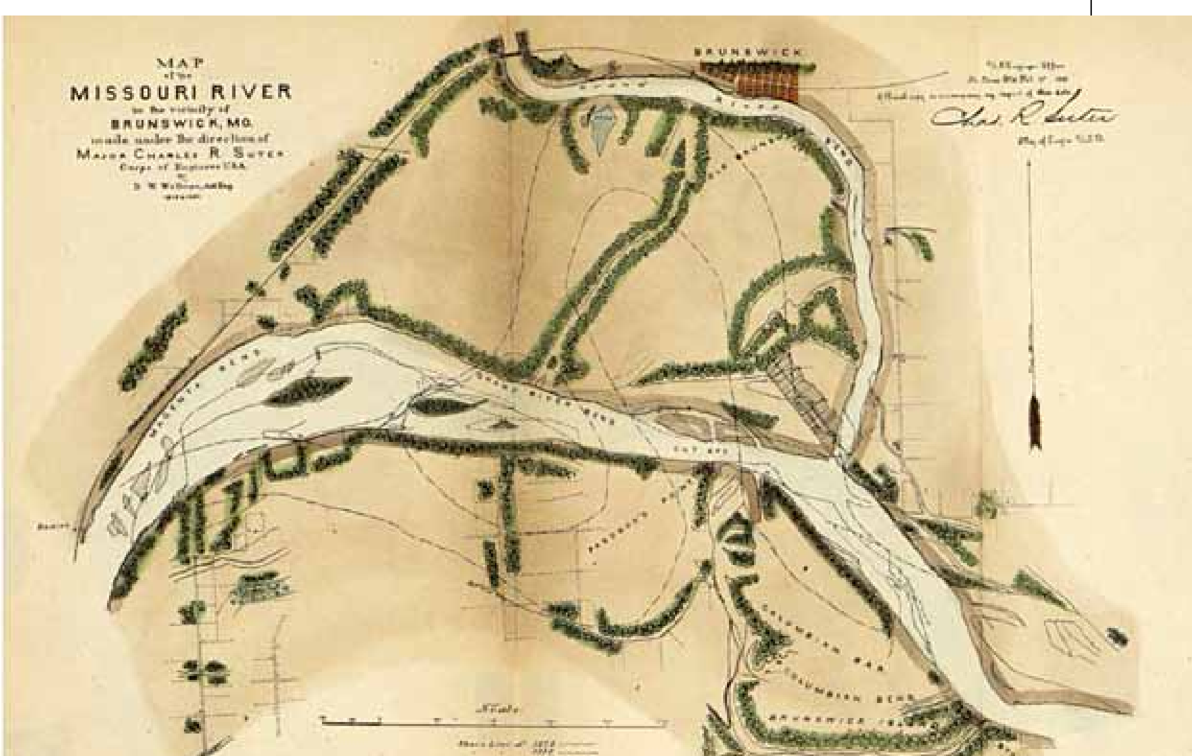
1. Restoration of a more continuous corridor of riverfront forest on each side of the current Missouri River channel from the Little Sioux River to the Missouri-Mississippi River Confluence area.
2. Restoration of larger tracts of the complex of riverfront, floodplain, and slope forest in the western part of the Kansas Reach north through the Nodaway Reach.
3. Restoration of larger tracts of floodplain forest on higher elevations interspersed with riverfront forest in the “long bottom” areas of the Osage and Grand River reach up to Glasgow, Missouri.
4. Restoration of small patches of floodplain forest that contains bur oak, next to riverfront communities in the Platte and Little Sioux Reaches.

5. Restoration of prairie and savanna complexes north of St. Joseph, in the eastern Kansas Reach to the Chariton River, and in the Missouri-Mississippi River Confluence Region.

6. Restoration of mesic prairie or slope forest alluvial fans/colluvial slopes on the edge of the LMR floodplain. Potential natural vegetation maps in the Map Set Appendix provide guidance for which community type is most suited to respective LMR areas.

7. Protection and restoration of remaining bottomland lakes throughout the LMR including attempts to restore more natural water regimes of alternating seasonal and interannual flooding and drying dynamics.

This report provides an "Application of Information (How-To)" section to help guide decisions about what communities can/should be restored at spatial scales ranging from broad ecoregions and regional floodplain corridors to specific tracts of land. It also suggests certain specific regional monitoring and evaluation needs and recommends that future restoration efforts be done in an adaptive management framework.



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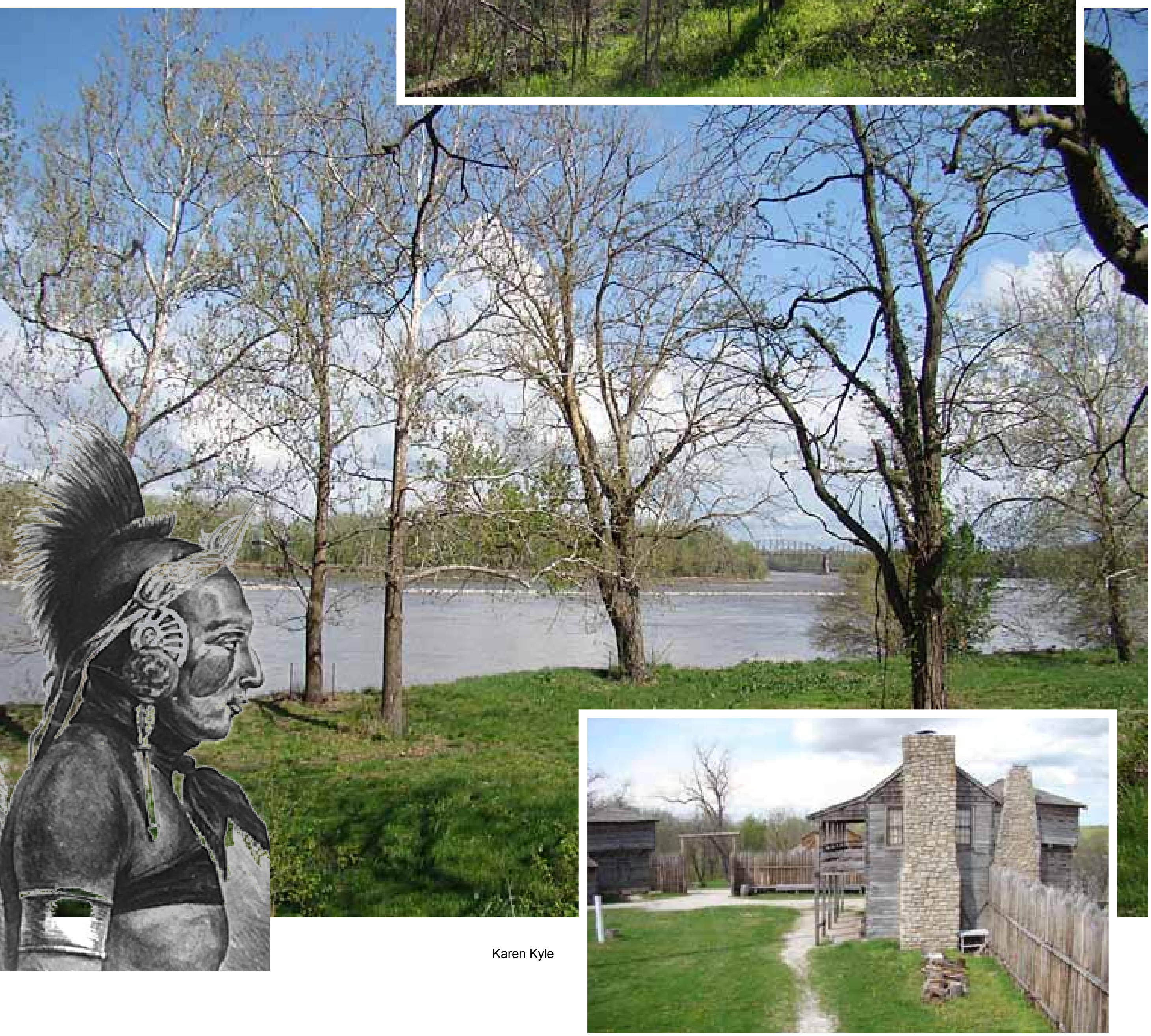
Originally established and built by William Clark in 1808.

Karen Kyle



Karen Kyle

INTRODUCTION

The contemporary Missouri River is the longest river in the United States (U.S.) flowing nearly 2,350 miles from the confluence of the Gallatin, Madison, and Jefferson rivers at Three Forks, Montana to its confluence with the Mississippi River near St. Louis, Missouri (National Research Council (NRC) 2002). The Missouri River Basin encompasses over 524,000 square miles and covers about 1/6 of the continental U.S., including all, or portions of, 10 states and the Canadian provinces of Alberta and Saskatchewan. The portion of the river below Gavins Point Dam near Yankton, South Dakota is commonly referred to as "The Lower Missouri River (LMR)," which is the longest undammed free-flowing river reach in the conterminous U.S. (Galat et al. 1999). Prior to major systemic alterations that began in the early 1900s, the Missouri River and its associated floodplain was one of North America's most diverse and dynamic ecosystems and included braided channels, chutes, and river sloughs; islands and sand bars; riverfront, floodplain, and slope forests, bottomland prairies and marshes; savanna woodlands; and abandoned channel oxbows and sloughs (Weaver 1960, Laustrup and LeValley 1998). While currently free-flowing, the LMR today is highly regulated by upstream reservoirs and water-control protocols and the channel is greatly restricted and altered in a channelized form (Ferrell 1993, 1996; Thorson 1994; Schneiders 1999). Additionally, most of the large river tributaries that enter the LMR have greatly altered land and water uses in their watersheds, channels, and floodplains (e.g., U.S. Department of Agriculture Soil Conservation Service (SCS) 1982, Sidle et al. 1989, Pitchford and Kerns 1994, Horton and Kerns 2002, Heitmeyer et al. 2011). Collectively, the many man-made changes to the Missouri River channel and other systemic ecological alterations within and upstream of the LMR have highly altered physical and ecological attributes of both the river and its floodplain (e.g., Funk and Robinson 1974, Halberg et al. 1979, Hesse 1996, and others).

Currently, many state and federal agencies, private conservation groups, and other entities (such as county and city parks, recreational land holdings, and private developments) are directing efforts to restore and enhance destroyed and degraded habitats along the Missouri River and its major tributaries. For example, the Fish and Wildlife Mitigation Project authorized under the Water Resources Development Act of 1986 initiated focused efforts to restore habitats along the Missouri River south of Sioux City, Iowa that were lost or degraded during river channelization and bank stabilization activities in the mid 1900s (U.S. Army Corps of Engineers (USACE) 2003). The project is authorized to purchase and restore up to 166,750 acres of land along the river to benefit fish and wildlife. Further, in 2000, the U.S. Fish and Wildlife Service (USFWS) released a Missouri River Biological Opinion that identified USACE management actions that could protect and recover several endangered fish and wildlife species (USFWS 2000). This "Opinion" was amended in 2003 to further identify restoration and management actions for select species (USFWS 2003). Subsequently, the USACE initiated the multi-partner Missouri River Recovery Program (MRRP) to achieve ecosystem recovery goals for the river and its floodplain ecosystem (USACE 2003, 2011). These recent federally mandated programs, along with many other state and local site-specific initiatives (e.g., Missouri Department of Conservation (MDC) 1989, Bouc 1998, McCarty et al. 2004, LaGrange 2010), demonstrate the interest and ongoing efforts to remediate past ecological damage in the LMR.

Clearly, a major challenge for the future conservation of this valuable ecosystem is to protect, restore, enhance, and manage critical parts of the historic LMR given the constraints of altered ecological processes and communities.

This report provides a landscape-scale hydrogeomorphic (HGM) evaluation of the terrestrial ecosystem (i.e., non-river channel) restoration options for the LMR floodplain from river mile (RM) 670 near the junction of the Little Sioux River south of Decatur, Nebraska to the confluence of the Missouri and Mississippi rivers (RM 0) near St. Louis (Fig. 1 and Appendix Map Set (MS)-1, Fig. 2), which contains names of most locations mentioned in this report text). An additional ongoing HGM evaluation will extend up river to RM 811 at the Gavins Point Dam near Yankton, South Dakota. HGM analyses are a valuable tool for understanding and evaluating ecosystem condition and processes as well as future acquisition, restoration and management options for large river systems in North America (see e.g., Heitmeyer 2008, 2010; Heitmeyer and Bartletti 2012). The HGM approach:

1. Uses information on geomorphology, soils, topography, and hydrology, along with selected reference sites, to identify potential habitat restoration options at a landscape-scale;
2. Provides discussion about the importance of emulating natural water regimes and vegetation patterns where possible;
3. Provides increased understanding of the potential to at least partly mitigate past negative ecological impacts to floodplain ecosystems;
4. Incorporates "state-of-the-art" scientific knowledge of floodplain processes and life history requirements of key fish and wildlife species; and

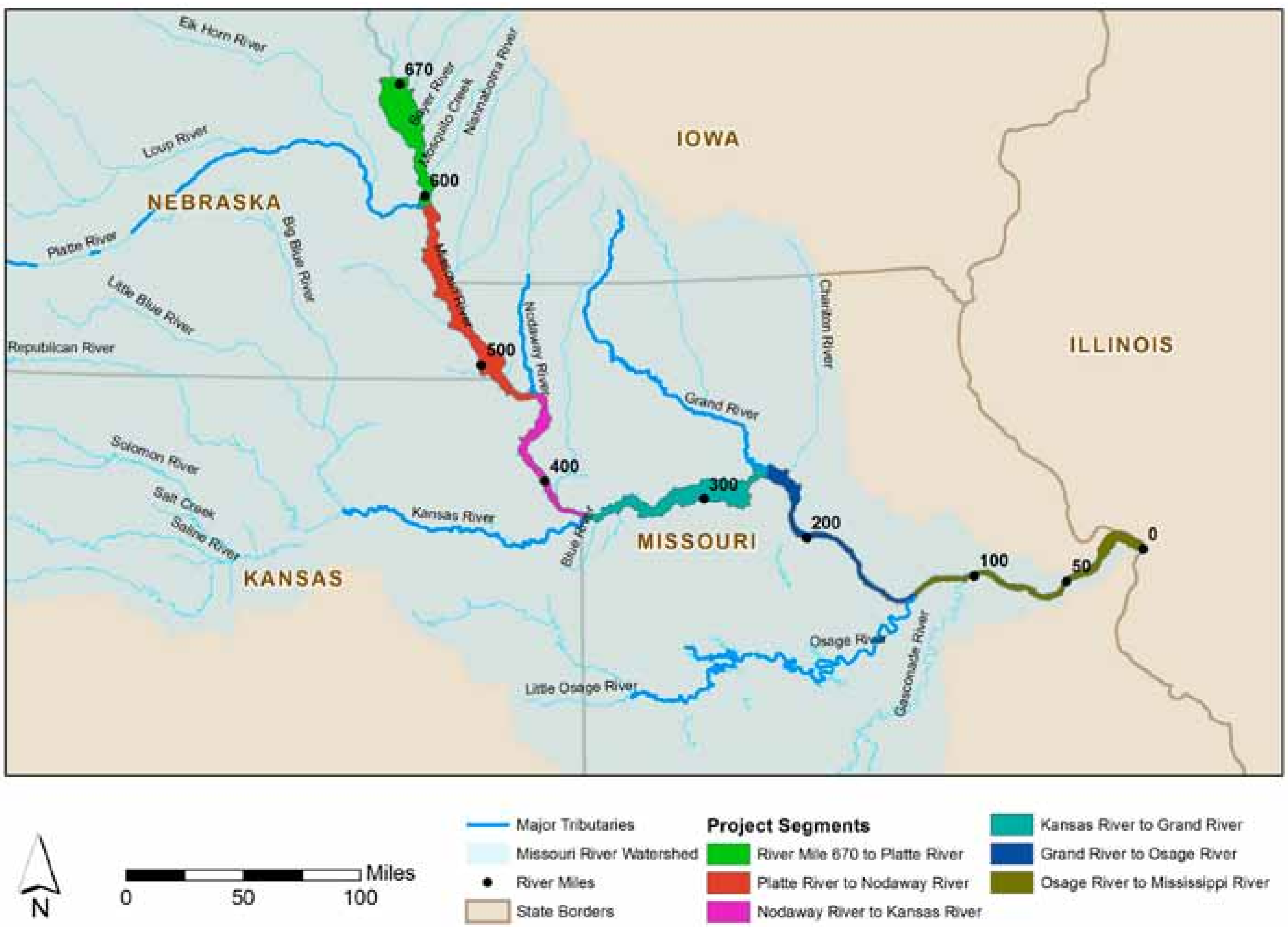


Figure 1. General location of the LMR study reaches from river mile (RM) 670 to RM 0.

5. Recognizes the desire to provide for multiple uses including recreational, agricultural, navigation, and educational opportunities for the public (Heitmeyer 2007, Klimas et al. 2009, Pastore et al. 2010, Nestler et al. 2010, Theiling et al. 2012, Heitmeyer et al. 2013).

In effect the HGM evaluation of the LMR in this report helps identify floodplain ecosystem restoration potential of this regulated part of the Missouri River system. As such, the report can serve as a tool to help guide land and waters uses within the corridor aimed at maximizing ecological functionality while considering recreational, navigational, and other interests along the river. The HGM evaluation in this report is directed at larger landscape-level understanding of restoration and management potential. It also provides a template of information that can subsequently be applied to individual sites, regions, and reaches (see e.g., Heitmeyer and Bartletti 2012) and is a foundation for development of specific strategies at detailed levels for both regional areas (such as the Lower Grand River ecosystem) and individual conservation lands (e.g., Heitmeyer et al. 2011, Heitmeyer and Newman 2014).

The objectives of this report are to:

1. Identify the pre-European settlement (late 1700s to early 1800s, hereafter referred to as the "presettlement" period) ecosystem attributes and ecological processes in the LMR.

2. Evaluate differences between the presettlement and current conditions in the LMR with specific reference to alterations in hydrology, community structure and distribution, and resource availability to key fish and wildlife species.

3. Identify restoration and management for potential floodplain community restoration

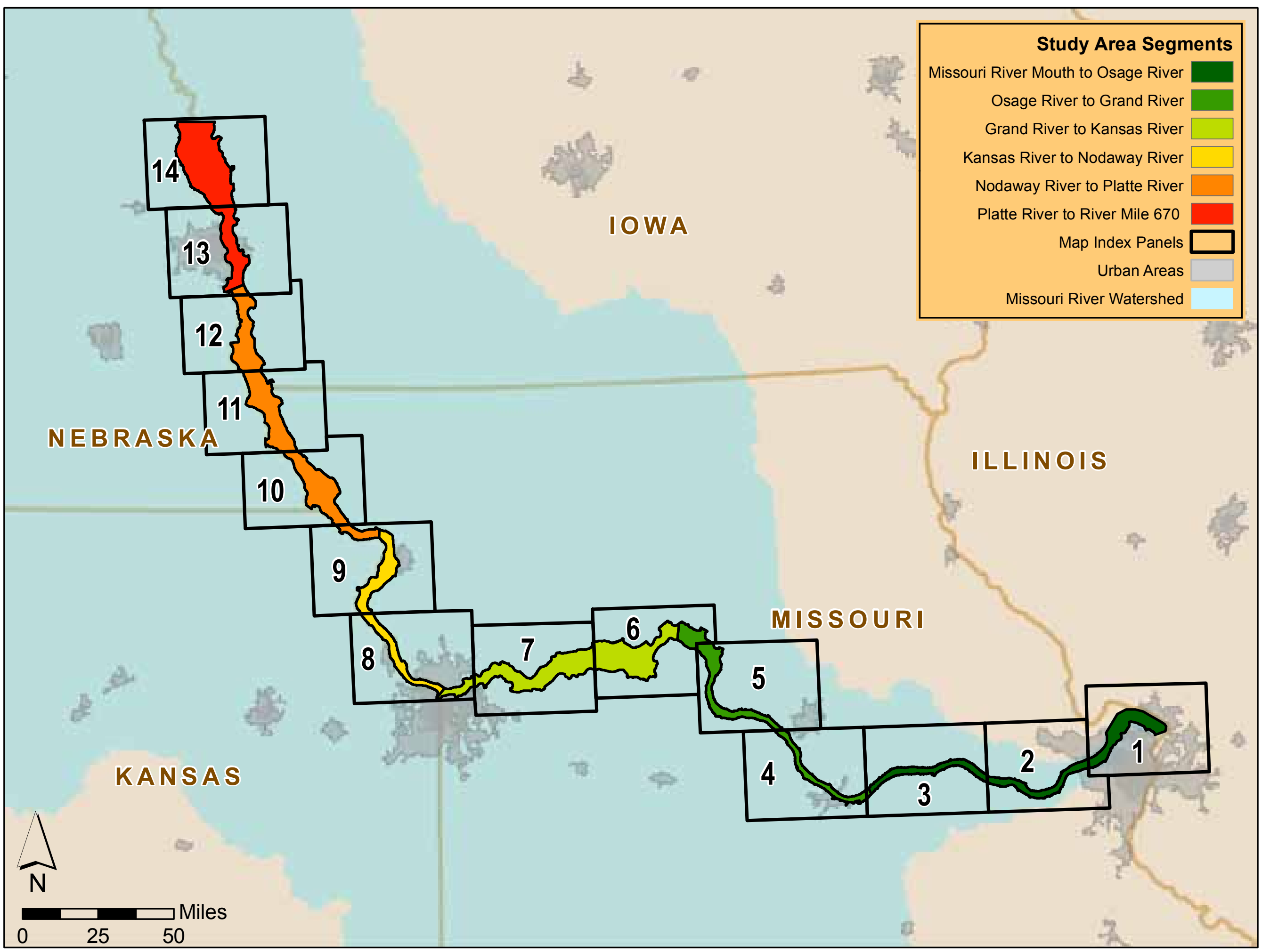


Figure 2. Location of the 14 map panels used to present HGM data for the LMR.

and ecological attributes needed to successfully restore specific habitats and conditions within the LMR.

The report is presented in three main sections with an emphasis on formatting information by river reaches or ecoregions. These report sections are: 1) The Historical LMR Ecosystem, 2) Changes to the Historical LMR Ecosystem, and 3) Potential Floodplain Ecosystem Restoration Options. A fourth report section offers guidance into "Application of Information (How-To)" from the Report. Sometimes referred to as "river valley segments" (Jacobson et al. 1999), the river reach ecoregions used in this report are: 1) RM 0 - RM 131 from the Missouri-Mississippi river confluence to the entry of the Osage River east of Jefferson City, Missouri (hereafter referred to as the Osage Reach); 2) RM 131 – RM 250 from the mouth of the Osage to the entry of the Grand River south of Brunswick, Missouri (Grand Reach); 3) RM 250 – RM 367 from the mouth of the Grand River to the entry of the Kansas River at Kansas City (Kansas Reach); 4) RM 367 – RM 463 from the mouth of the Kansas River to the entry of the Nodaway River just north of St. Joseph, Missouri (Nodaway Reach); 5) RM 463 – RM 595 from the mouth of the Nodaway River to the entry of the Platte River near Omaha, Nebraska (Platte Reach); and 6) RM 595 – RM 670 from the mouth of the Platte River to the entry of the Little Sioux River west of Pisgah, Iowa (Little Sioux Reach) (Fig. 1). The LMR floodplain in these six reaches contains nearly 1.5 million acres of land in about 50 counties in four states. The division of the LMR into these six reaches separates the study area into areas between substantive tributaries that have relatively uniform physiographic and geologic characteristics and somewhat similar lengths (96 to 132 miles). All of the selected tributaries that represent LMR separation points add greater than approximately five percent of the cumulative drainage area and/or drains an area of hydrogeomorphically different hydrologic responses, sediment yields, or water-quality contributions. Maps of HGM attributes covered in this study are presented in 14 panels, each about 40 miles long, which cover the six reaches (Fig. 2, and Map Set Appendices MS-1 to MS-14).

Karen Kyle

THE HISTORICAL LMR ECOSYSTEM

GEOLOGY AND GEOMORPHOLOGY

As the modern day Missouri River travels nearly 2,350 miles from Gallatin, Montana to St. Louis it drains about 524,000 square miles from 10 U.S. states and the southern parts of Alberta and Saskatchewan in Canada. The elevation of this area drops about 13,600 feet and crosses a variety of bed rock and continental geological surfaces formed and deposited over geological time. During the Oligocene Epoch (33.9 to 23 million years ago), the Rio Grande River was the major drainage system for North America (Galloway et al. 1991), but continental tectonic activity and climate variation reorganized continental drainages and established the Mississippi River as the dominant mid-continent drainage system by the end of the Tertiary Period (which ended about 2.6 million years ago) when it had actively prograded to the Gulf of Mexico (Frye et al. 1965, Winker 1982, Saucier 1994). Sequential continental glaciations rearranged the interior drainage of North America several times and established the historical routes that eventually morphed into the modern Missouri River course. Prior to the Pleistocene Epoch (2.5 million to 11,700 years ago), the ancestral rivers of the Northern Great Plains including the Missouri, Yellowstone, Little Missouri and Cheyenne rivers drained north and east to Hudson Bay, while rivers in the Middle and Southern Great Plains such as the Niobrara, Platte, and Kansas rivers drained east and southeast to join the Mississippi River and flow to the Gulf of Mexico (Todd 1914, Fisk 1944, Meneley et al. 1957, Howard 1960, Dreeszen and Burchett 1971 – and see Fig. 3, Flint 1971, Wayne et al. 1991, Langer et al. 1994). The ancestral Platte River followed its course from Colorado through Nebraska and into northwest Missouri where it then flowed across northwest Missouri and down the course of the modern Grand River where it then joined the ancestral Kansas River near Brunswick, Missouri (Dreeszen and Burchett 1971, Simms 1975, Anderson 1979, Whitfield 1982, Aber 1991, Whitfield et al. 1993). The ancestral

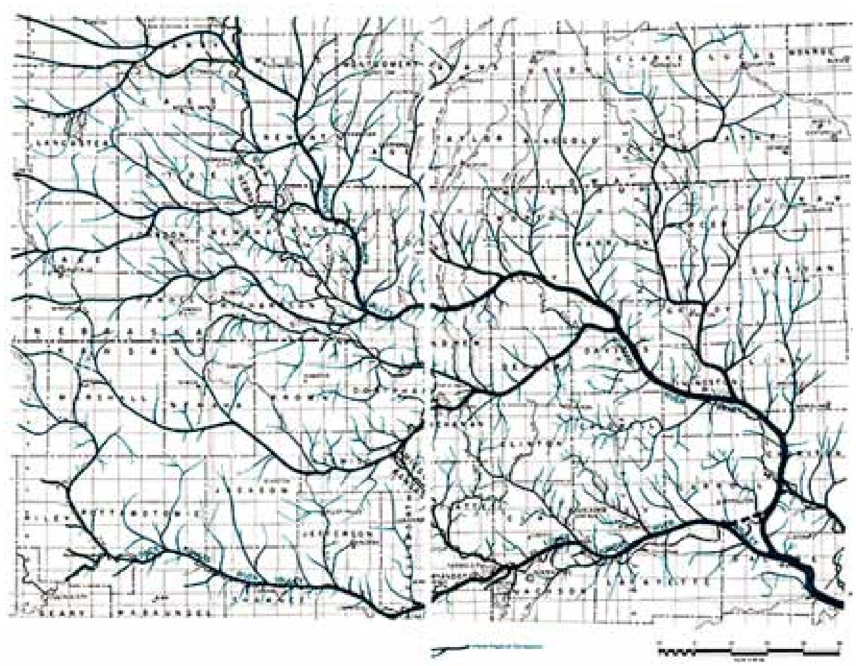


Figure 3. Preglacial drainage map of the Lower Missouri River Basin (from Dreeszen and Burchett 1971).

Kansas River flowed through Kansas and then generally down the channel course now occupied by the Missouri River between Kansas City and Brunswick. The precise course of the ancestrally joined Kansas and Platte rivers (now Missouri River) from Brunswick to St. Louis is not known, but may have occupied the current Missouri River channel, or conversely cut across eastern Missouri from about Boonville, Missouri to St. Louis instead of turning south at Boonville as it does today (see discussion in Whitfield et al. 1993).

Glaciations of the early Pleistocene, followed by the Illinoian and Wisconsin glaciations of the middle and late Pleistocene rearranged the interior drainages of North America, and the modern Missouri River marks the approximate southern extent of pre-Illionian glaciers (Guccione 1982, Blum et al. 2000). Rivers that formerly flowed east across the Great Plains were dammed and diverted south while the advancing ice buried earlier rivers that drained the north and central parts of the continent. In effect, the Missouri River from Great Falls, Montana to Kansas City became a "glacial-margin" stream (Langer et al. 1994). As ice advanced, the east-flowing streams and lakes that formed because of the ice dams would spill into adjacent basins. When ice retreated, the rivers would either remain in the "new" ice-margin course (termed a "by-pass" of the former course) or move back to reoccupy former channels. It is generally believed that the Missouri River Valley in the LMR north of Kansas City represents a new "by-pass" course formed by ice advance. In contrast, at least some stretches of the Missouri River between Kansas City and St. Louis may represent "reoccupation" of preglacial channels. It remains unclear whether the pre-Illinoian ice advanced south of the modern Missouri River Valley between Kansas City and Jefferson City (Bretz 1965, Anderson 1979, Aber 1991, Hawker 1992, Whitfield et al. 1993, Soller 1998, Aber 1999), but most geological maps suggest glacial advance south of the current river location from about Boonville to Napoleon, Missouri and perhaps below the Missouri-Mississippi River confluence at St. Louis (see Unklesbay and Vineyard 1992:22). One example of reoccupation of a former course includes a shift in the Missouri River channel to the north from a southern "by-pass" during glacial advance in the Blue and Little Blue River areas east of Kansas City (Kelly and Blevins 1995). Another glacial "by-pass" of the former river course during glacial maxima times may have occurred near Miami, Missouri where the ancestral river was diverted south through the valley of the Lamine River and then to the Missouri River (Todd 1914, Whitfield et al. 1993); during the post-glacial period the river rebounded to its current northern location.

The Missouri River Valley is generally divided into three geophysical regions: 1) the Upper or Mountain District, 2) the Plains District, and 3) the Lower Valley Region or District (Broadhead 1889, Spooner 2001). These districts today essentially represent the: 1) free-flowing Upper Section, 2) the impounded Middle Section, and 3) the Lower Channelized Section. The LMR area in this report is within the third, lower valley area. The surficial geomorphology of the LMR varies substantially from the northern Little Sioux to southern Osage reaches. Clearly, the geological chronology of channel occupation during glacial and post-glacial periods influenced the character of regional floodplains through variable sediment sources and quantities; alluvial deposition and scouring; and lateral meandering, sinuosity, and form. The width of floodplains reflects bedrock characteristics and incision into this bedrock (Bluemle 1972, Jacobson et al. 2009). Further, as an example of physical landform variation, Missouri River floodplain stretches are often referred to as "long" or "loop" bottoms, where long bottoms are terminated where the river cuts diagonally across the valley and loop bottoms are relatively small and partly enclosed by a single curving bend or loop of the river (Schmudde 1963, Fig. 4).

Surficial geomorphology of the LMR can be differentiated into active channel, meander belt (floodplain), alluvial terraces, and bordering colluvial landforms downslope of bluffs (Fig. 5). Additionally, geomorphic surfaces within floodplains reflect former river channels and courses including remnant oxbows and sloughs; former and current natural levees, crevasses and crevasse splays, and point-bar "ridge-and-swale" complexes (Fig. 6, Holbrook et al. 2005). Obviously, the active channel contains most of the main stem discharge and includes the channel bed(s), sandbars, and banks of the river. The historical form of the Missouri River channel in the LMR channel varied from single- to multi-channel geometry, which often separates a "straight" or "meandering/wandering" form vs. a "braided" or "anastomosing" form (Fig. 7) (Bridge 2003, Holbrook et al. 2005, Kashouh 2012). During normal historical flows the river channel was characterized by

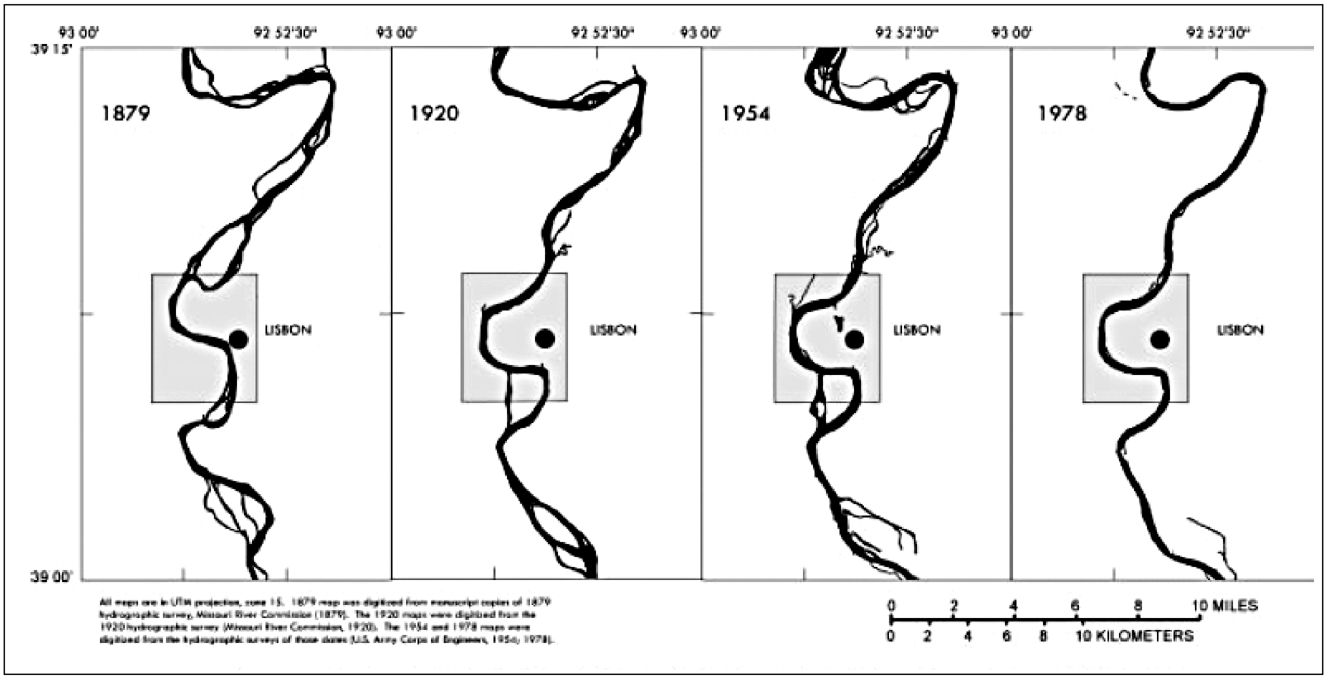


Figure 4. Example of "long" and "loop" bottom floodplain landforms in the Grand Reach of the LMR (from Jacobson et al. 1999).

continuous bank erosion along with shifting configuration and island-bar form and location (Schmudde 1963); it is estimated that about 1/3 of the floodplain of the LMR was reworked by the river between 1879 and 1930 (Schmudde 1963, Appendices MS-2, MS-3). The meander belt represents the land surface that the river channel(s) formerly occupied and where sediment deposited during the Late Holocene Epoch. The ridge-and-swale topography of the meander belt reflects the lateral migration pattern of former river channels and the alternating remnants of point bars (the ridges) vs. in-filled former channels (swales). Remnant ridges tend to be sandy while swales contain finer texture silt and clay (Holbrook et al. 2006). Terraces represent older, non-eroded, Pleistocene-age floodplain floor surfaces, and colluvial slopes and fans are sites where streams or drainages eroded, and then deposited, upland soils on floodplain edges. Optically stimulate luminescence (OSL) dating techniques recently have been used to prepare surficial geomorphology maps for LMR areas north of Omaha and various stretches from Kansas City to Jefferson City (Appendix MS-2, and see Rittenour et al. 2005, Holbrook et al. 2005, 2006, Kashouh 2012). Additionally, geomorphic land sediment assemblage (LSA) maps also are available for the Missouri-Mississippi river confluence area (Hajic 2000, Woerner et al. 2003).

Downstream from Gavins Point Dam, the Missouri River crosses the southern boundary of the Wisconsin glaciations (King and Beikman 1974) and extensive deposits of late Pleistocene outwash underlies a broad floodplain that is up to 12 miles wide. Variations in valley width throughout the LMR generally reflect local and regional variation in the erodibility of bedrock that underlies the valley walls. Upstream of RM 625 the river valley is wide and within shale-dominated Cretaceous rocks, while areas near and south of Omaha contain more resistant carbonate dominated Pennsylvanian rocks (Halberg et al. 1979). Consequently, the Little Sioux Reach has a sharply divided geomorphology north and south of the current Boyer Chute National Wildlife Refuge (NWR) (Appendix MS-2). North of Boyer Chute NWR, the wide floodplain contains numerous abandoned channel depressions, splays, crevasses, and higher elevation terraces, while the southern area to the confluence with the Platte River is narrow, incised, and with relatively few remnant river channels (Appendix MS-3). OSL techniques suggest that the northern part of the Little Sioux Reach transitioned from a meandering to a braided river system about 1,600 years before the present (BP) as climate shifts in the Northern Great Plains caused drier warmer conditions and generally reduced discharge and sediment inputs, which led

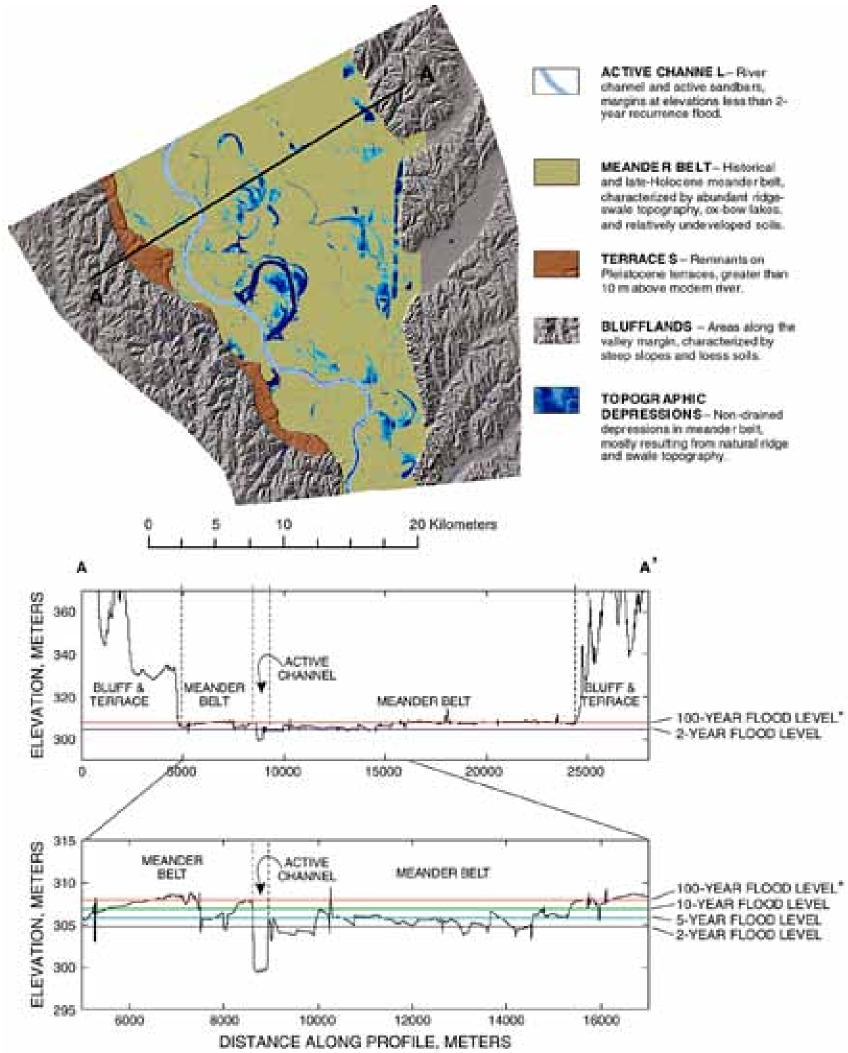


Figure 5. Classification of LRM geomorphic landforms and relations to hydrology, using an example from near DeSoto NWR, RM 630-655. (From Jacobson et al. 2011).

to less widely meandering and channel cut-offs first in the lower southern parts of the LMR about 1,200 to 3,400 BP, and then later to the area north of the Platte River entry (Kashouh 2012).

The entry of the Platte River just south of Omaha substantially alters the character of the Missouri River and its downstream floodplain. As mentioned previously, prior to the early Pleistocene glaciers, the Platte River flowed south from Omaha to some point(s) north of St. Joseph where it then crossed northwest Missouri and flowed down the current Grand River drainage route. During glacial advance, the Platte River was diverted south to join the Kansas River at the current location of Kansas City. This glacial "by-pass" forced the river to incise Pennsylvanian bedrock, which now is usually 30 feet below the land surface, with the covering of alluvial fill comprised of Pleistocene and Holocene gravels, sands, and silts transported from glaciated regions to the north overlaid by recent alluvium (Appendix MS-4). The watershed of the Platte River extends west to Colorado and carries high sediment loads. Post-glaciers, wind-blown loess was deposited in thick hills along the east side of the floodplain. As such, the current floodplain widths in the Platte Reach are marked and defined by conspicuous rapidly rising loess bluff lines. The Platte Reach contains relatively wide floodplains mostly in a long bottom form until the river course bends east just north of St. Joseph. The Missouri River occupied a relatively narrow zone of change from the time of the Lewis and Clark Expedition in 1804 to the present (Moody et al. 2003, Appendix MS-3) with the exception of the marked cut-off at the Big Lake area. To date, OSL geomorphic mapping has not been completed for the area between Omaha and Kansas City.

The area south of the entry of the Nodaway River generally has a reduced loess deposition area from north to south and further contains differences in sediment and water volume entry from the Nodaway River (Horton and Kerns 2002). The Nodaway Reach is relatively young compared to the river areas above and below it (see discussion above on ancestral Platte-Missouri River courses during pre-glacial periods). The Missouri River floodplain width of the Nodaway Reach is relatively narrow and reflects its formation by incision through resistant bedrock (see Jacobson et al. 2009). With the exception of the area just north of Atchison, Kansas the Nodaway Reach is dominated by loop bottoms especially just north of Kansas City. Many remnant river cutoffs exist in the reach such as at Lewis and Clark State Park, Bean Lake, and Lake Contrary (Appendix MS-3). A few small colluvial fans occur on the fringe edges of the Missouri River floodplain where small creeks/streams enter the river valley.

The area between Kansas City and the entry of the Grand River represents the ancient channel/course of the Kansas River that drained portions of central and northern Kansas. The stretch between Kansas City and Camden, Missouri has a fairly narrow floodplain width, generally higher elevations where sediment aggradation has occurred (Jacobson et al. 2009), and contains mainly loop bottoms, whereas the floodplain east to the entry of the Grand River is wide, lower elevation, and long bottom form except for the large river bends east of Waverly, Missouri (Appendix MS-3). The broader alluvial plain east of Camden is an area underlain by less resistant Pennsylvanian limestone and shale , which enabled the river to meander widely and erode a wide lateral floodplain that is considerably lower elevation than in the western Kansas Reach (Nigh and Schroeder 2002). This east Kansas Reach area also represents the location where the Missouri River rebounded or relocated north from its location in the Little Blue River drainage during the Pleistocene glaciers. Further east, the confluence of the Grand River at Brunswick, which represents the ancestral Platte/Missouri River course, is a location of terrace and tributary fan development where massive quantities of post-glacial sediments were deposited (USACE 1989, Pitchford and Kerns 1994). The area east of Miami to Glasgow, Missouri also appears to have been covered by glacial till when glacial ice forced the river to move south into a glacial "by-pass" route in the current Lamine River location. As glacial ice retreated, the river returned north to a pre-ice course, and consequently left a wider floodplain landform. The narrow loop bottoms west of Camden contain several large

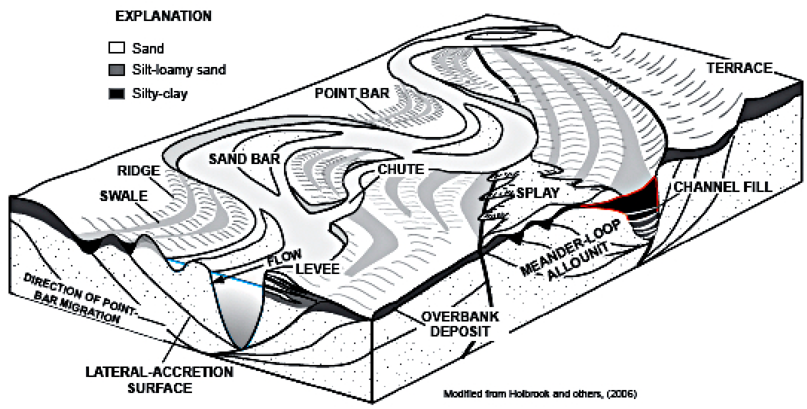


Figure 6. Geomorphic surfaces in the LRM. Meaner loops are formed by lateral migration of point-bars and smaller lateral bars that are attached to the channel boundary on the inside of meander loops. Lateral migration occurs in stages, producing a series of lateral-accretion surfaces, w which manifest on the surfaces as ridges and swales oriented sub-parallel to the river channel. Point bars tend to decrease in grain size upward from sand to fine gravel at the base to silt and clay at the top. Channel fills record sedimentation in channels that have been abandoned from the active flow by local meander cut off, or shifting of the entire channel to a new location on the floodplain (avulsion). Channel fills are generally floored with the coarse material typical of the bed load carried by the river. Channel fills are recognized as long accurate and straight trends of low topography with widths equal to or less than the forming channel. (From Jacobson et al. 2007 as modified from Holbrook et al. 2006).

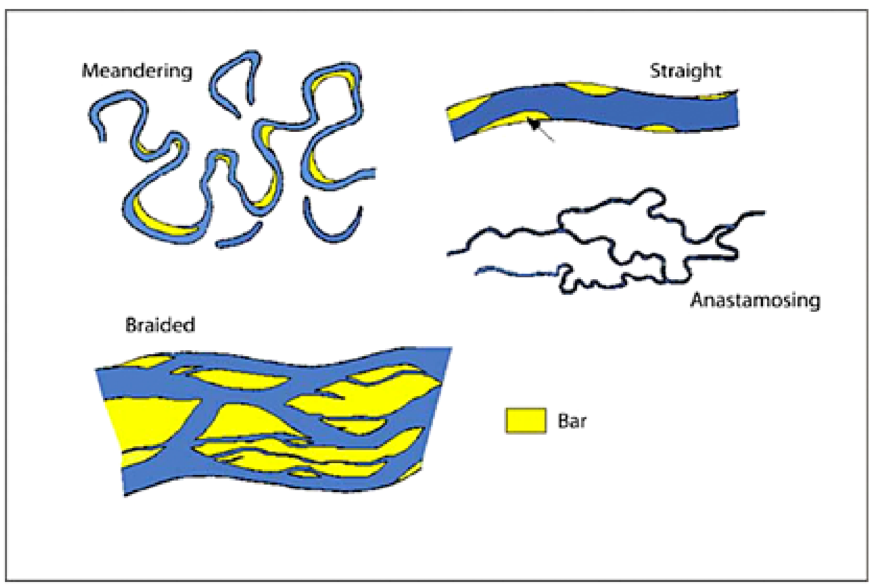


Figure 7. Types of river channel patterns. (From Kashouh 2012 as modified from Bridge 2003).

remnant oxbows such as Cooley and Sunshine lakes, while the eastern part of the reach does not contain recent river cutoff oxbows.

The Missouri River floodplain between the Grand and Osage rivers is on the margin of the Ozark Plateaus and is cut into relatively uniform Paleozoic cherty limestone, cherty limestone, and minor amounts of sandstone and shale (Jacobson et al. 1999). The area upstream of Glasgow is relatively wide and is similar to the eastern part of the Kansas Reach, which is arrayed on relatively soft Pennsylvanian-aged sedimentary rocks dominated by interbedded limestone and shale (see above discussion of the geology of the Kansas Reach). This area north of Glasgow is also highly influenced by the entry of the Grand River (which previously was the ancestral Platte-Missouri River course) and its large sediment loading and frequent flooding (see discussion in Heitmeyer et al. 2011). The historic Chariton River also joined the Missouri River just north of Glasgow and it and Grand River combined to create a wide mound of sediment deposition or tributary fan in this area. Historical channel meandering at the Grand-Chariton-Missouri confluence seems to have been common, for example the presence of Dalton Cutoff, likely because of temporal variation in discharge and sediment dynamics from the Grand (historical Platte-Missouri) River (Appendix MS-3). Below Glasgow, the river corridor is often less than five times as wide as that north of Glasgow. The narrow downstream part of the Grand Reach has few remnant alluvial terraces and is bounded by steep bedrock bluffs. Here the valley is entrenched in harder, more resistant Ordovician and Mississippian sedimentary rocks dominated by limestone and dolomite. This narrow bedrock-confined reach tends to confine large flood events, but has promoted frequent scouring and secondary currents where the channel impinges on the rock valley walls (Jacobson et al. 1999). Below Glasgow, the river has alternating reaches of high and low sinuosity and loop bottoms are common including the larger Lisbon Bottom-Jameson Island and Plowboy Bend-Marion Bottom complexes. Typically the floodplain south of Glasgow is filled with about 60 feet of highly permeable glacial outwash overlain by post glacial sand and gravel in the southern part and interbedded sand, silt, and clay in the uppermost areas (see Spooner 2001).

The Missouri River floodplain from the entry of the Osage River to the confluence of the Missouri and Mississippi rivers crosses the Ozark Uplift where geological strata gently dip to the north and northwest (Nigh and Schroeder 2002). The bedrock is about 50-100 feet below the surface and is highly resistant, which caused a historic narrow incision of the river course and a relatively narrow floodplain west of the confluence area (Jacobson et al. 2009). The location of the river marked the southern extent of Pleistocene glaciers and floodplain relief is low. The geomorphology of the confluence area is dominated by the entry of water and sediments from the Missouri and Illinois rivers to the Mississippi (see discussion in Heitmeyer and Bartletti 2012). A peninsula, known as the St. Charles Bottom, formed between the Mississippi and Missouri rivers and is a huge sediment mound, or terrace, bisected by small tributary channel belts. This reach has significant upstream backwater influence caused during high flow and flood events on the three confluence rivers, which is reflected in the wide alluvial fans built at the mouths of the Missouri and Illinois rivers. Several large abandoned channels formed in cutoffs of the river confluence locations, such as Marias Temp Clair.

SOILS

U.S. Department of Agriculture (USDA) General Soil map (STATSGO) and Soil Survey Geographic data base (SSURGO) are contemporary sources of soil information for the LMR (USDA 2009). This information provides a broad based inventory of soils and non-soil areas that occur in repeatable patterns on landscapes (Soil Survey Staff 1993). Soil attribute data, coupled with hydrogeomorphic information, helps understanding of the similarity of formation and structure of various LMR surfaces and locations and their potential to support various plant and animal communities (see e.g., Sprecher 2001, Jacobson et al. 2011:305-308). As with geomorphology, soil type influences water and nutrient retention, movement, and cycling, site and regional fertility, biochemical constituency, and availability of resources to plants and animals.

The complex geomorphology of the LMR described above created a heterogeneous mosaic of soils related to origin of parent materials, depth and type of scouring and deposition, water retention and drainage capacity, and vegetative cover (Appendices MS-4, MS-5). Most soils in the LMR can be classified as mollisols, entisols, and inceptisols. Entisols are widespread throughout the floodplain and are recently deposited alluvial sediments that generally do not have well developed subsoils. Many Entisols retain the textural and color stratification of the original flood-deposited material. Inceptisols are generally found on more stable, higher elevations that have developed soil structure in the subsoil. Soil texture is highly variable in these soil types, depending on the floodplain landform. For example, soils in crevasse splay deposits typically are sandy, soils on natural levees are loams, and backswamp and abandoned channel sites have mainly clay veneers over underlying sand and gravel. Mollisols generally formed on older terraces under prairie or wet bottomland herbaceous communities and have thick, dark surface layers with relatively high levels of soluble bases, such as calcium and magnesium. Some of these soils reflect eroded loess material that was common throughout the LMR, especially in the northern Little Sioux, Platte, and Nodaway reaches. Most mollisols have silt loam or loam surface layers.

Several thousand individual soil taxonomy types are present in the LMR (USDA STATSGO datasets) and it is beyond the scope of this report to describe or present maps of all individual soil units. Specific soil data and maps (both older and more recent) are available from the STATSGO datasets and individual county soil reports and maps (e.g., Watkins 1921, Grosser and Landtiser 1978). In an attempt to categorize major soil texture types (i.e., sands to clays), we prepared consolidated soil type maps (Appendix MS-4), and LMR soils are also categorized by water retention capacity (Appendix MS-5, Jacobson et al. 2007, 2011; Chojnacki et al. 2012). Many soil types in the LMR are mapped by SSURGO as soil "complexes." If a soil complex was composed of similar soil types or series of soils they were generalized to the predominant soil component type. If soil types were dissimilar they were generalized based on the major soil series types and hyphenated. Generally, certain general soil categories tend to be associated with specific geomorphic surfaces (see Fig. 6), but specific sites on similar geomorphic surfaces may have different depths and types of surface soils. For example, the depth of veneers of silts on point bar and glacial terrace surfaces varies greatly, and lenses of underlying sand and sometimes gravel may be near (within a few feet of) the surface and can be readily exposed by topographic change or scouring.

Abandoned channels including bottomland lakes, sloughs, and older chutes contain soil distribution that reflects time and location of separation from the main river channel. The upper portions of abandoned channel "arms" usually fill with a short wedge of sand or silty sand, while the remainder of the depression is filled with fine-grained clay and silty clay. Over time, older abandoned channels gradually fill with sediments and eventually become obscured by subsequent meander belt deposits. Many areas of this mixed soil configuration occur in the oxbow lakes of the LMR. Point bar surfaces, and the new terraces and ridge-and-swale topographic features they include, reflect lateral accretion deposits formed during horizontal migration of river channels. As channels migrate they laterally build a bar of silt and sand on the inside point bar "ridge" and create a cut or "swale" on the outside bank. The formation of a series of lateral bars creates a corrugated surface of silty sand ridges and alternating clay or silty clay filled depressions. These formations occupy large areas of the active floodplain surfaces in the LMR.

Old and new islands and bar surfaces historically were arrayed in parallel bands in and near the active channel of the Missouri River (e.g., see Hesse 1990, 1996). These areas in the active floodplain have less developed top stratum than older alluvial meander ridge-and-swale surfaces and often contain a thin, often temporary, veneer of recently deposited natural levee material. Soils on islands and bars range from sand and gravel at the base near the Missouri River to highly irregular top strata of silty sand ridges and moderately deep silty clay and clay filled river chutes. These surfaces and soil types occur throughout the LMR. Backswamp or floodplain depressions occur in many poorly drained paleo-channel floodplain sites. Soils in these areas are almost entirely clay and silty clay 15-30 feet thick; occasional thin lenses or lamina of silt and sand may be present. Some backswamp sites, especially those in older floodplain depression areas have considerable organic material in surface layers in the form of disseminated plant particles, peat, and woody residue.

Alluvial fan and colluvial slope deposits at the base of upland bluffs and at tributary confluences radiate outward onto the floodplain and have variable shape and size depending on volume and velocity of material that has eroded from the bluffs or is carried as suspended sediment by tributaries. These fan and slope areas are present throughout the LMR, but are most common in the west central part of the Kansas Reach and in sites north of Kansas City.

Soils on alluvial fans are mostly redeposited loess silts with lenses of sand and silty clay. Alluvial fan soils generally are relatively loose and well drained compared to clay or silt-veneered floodplain surfaces (Appendix MS-5, Jacobson et al. 2007, Chojnacki et al. 2012). Larger tributary fan or sediment "mound" areas, such as at the mouth of the Grand and Chariton rivers and in the Missouri-Mississippi-Illinois river confluence, have older deeper veneers of clays and silts over underlying sand and gravel.

Natural levees are low wedge-shaped ridges that border one or both sides of river channels, either recent or ancient. Soils on natural levees usually are sandy silts, silts, and sometimes silty clay. Natural levees are highest and contain more coarse material near the active, more defined channels, of current LMR rivers, and they decrease in height and sediment size away from the main channel. Some remnant natural levees also are present along older abandoned channels in the LMR, while those associated with chutes and bars and more braided channel morphology farther north in the LMR usually are less than five feet thick

Older terraces in the LMR are mostly Pleistocene-age sand and gravel deposits. These terraces often rise 25-35 feet above the floodplain and contain minor sand lenses in some areas. Most terraces have veneers of loess, silts, and silt loams over the deeper sand and gravel stratigraphy. Usually these veneers are relatively thin, but in some sites paleo and active floodplain channels and overbank flows have dissected the terraces and deposited thicker silt and some clay materials.

The dominant alluvial sediments deposited by the Missouri River in the LMR are calcareous, and the alluvial floodplain has free carbonate rocks within many profiles. This causes soils to generally have neutral to slightly alkaline pH values. In contrast, some tributary floodplains and the confluence areas of them, such as the Grand River have neutral to strongly acidic profiles, and few if any carbonate rocks (Nigh and Schroeder 2002).

TOPOGRAPHY AND ELEVATION

USGS quadrangle topographic maps are available for the entire LMR (Appendix MS-1). Additionally, recently completed Light Detection and Ranging (LiDAR) elevation maps now also are available (Appendix MS-6). The topography of the LMR reflects a broad system-wide rate of fall of the Missouri River and its floodplain along with regional and site-specific variation related to geomorphic/fluvial dynamics and surface formation/evolution. River slope for the entire Missouri River varies from about 100 feet/mile in the Rocky Mountains to less than 3 feet/mile in the LMR (USACE 1985). Individual reaches and shorter river stretches have substantial variation in rate-of-fall, for example the river drops only about 0.9 feet/mile from St. Joseph to Kansas City. Flow-recurrence inundation mapping related to flood frequency (Appendix MS-7) also indicates regional trends in elevation gradient and diversity within the LMR areas. For example the floodplain north of Omaha quickly rises over 30-40 feet above the channel, while most of the floodplain along the Nodaway Reach is less than five feet above mean river height.

CLIMATE AND HYDROLOGY

The large area of the LMR (about 1.5 million acres) and its even larger river watershed (about 524,000 square miles) encompasses great variation in climate and hydrology. At the local level, site-specific and regional temperature and precipitation events and trends impact river reaches somewhat independently. In contrast, at a watershed scale, the cumulative impacts of a variable climate significantly affect downstream hydrology. Hydrological effects are not limited to the Missouri River proper, but also are highly influenced by the many tributaries and their watersheds (e.g., SCS 1982, USACE 2004a). The following discussion about LMR climate and hydrology attempts to summarize certain key data about the system as a whole and within reaches, respectively. Detailed summaries of climate and river hydrology trends in each LMR reach are presented in Appendices A and B. This discussion by necessity includes trends in climate over long-term periods with relevance to future climate change. The great impacts of river channelization and impoundment also are discussed to some degree to put historical patterns into perspective.

The LMR lies in a transitional mid-continental position and experiences "extremes" that in some years resemble areas to the east and south (i.e. wetter and warmer), while in other years resembles the climate of areas to the north and west (drier and cooler) (University of Missouri Climate Center 2010).

Most of the Missouri River watershed lies to the west and south of the river. The largest tributaries to the Missouri River flow from west to east or from southwest to northeast (meeting the Missouri River's right bank, as facing downstream). Due to the position of the headwaters in the Rocky Mountains, and the relative contribution of flows draining from more arid lands to the west, pre-regulation (i.e., prior to 1954 when flow regulation became significant on the upper Missouri River dam system, although it should be recognized that dam construction began prior to 1940, and there was some influence on flows of the LMR throughout this period) flow dynamics of much of the Missouri River have predominately reflected the drier, cooler climatic conditions of the western portions of the basin (Galat and Lipkin 2000). The majority of lands within the watershed are semi-arid and thus Missouri River flows are considered low in comparison to its total drainage area. The snow-melt and thunderstorm run-off produced in the Rocky Mountains and Great Plains was, and still is, the primary driver of Missouri River flow regimes. Tributaries from the wetter portions of the watershed (Iowa and Missouri) had significant influence over the downstream river hydrology regardless of the relatively small percentage of the drainage area that they represent. These lower reaches of the watershed provide a greater percentage of total flow per drainage area size to the lower portions of the Missouri River. It is not until the Missouri River passes the mouth of the Kansas River that there is a relative balance between the size of the watersheds of the right bank and left bank tributaries. The position and direction of the major tributary watersheds are important when considering the general east to west direction of storm systems moving across the region and how precipitation from these storms accumulate and augment Missouri River flows (USACE 2004a).

The climate of the Missouri River Basin, as a whole, is controlled by air mass circulation from the Gulf of Mexico, the Northern Pacific Ocean, and the northern polar region (USACE 1985). Climate data for the LMR was summarized for five stations that represent the Osage to Little Sioux reaches (Appendix A, Figs. 8, 9). Throughout the LMR, spring to fall precipitation is mostly rainfall, often in thunderstorms and heavy rain, that causes localized flooding of streams and tributaries to the Missouri River. On average, measurable precipitation occurs between 70-105 days per year across the study area, and generally increases with distance downstream. This range may have been slightly greater in the past, however, since the number of days with measurable precipitation per year has slowly increased in the upper portion of the study area (near Logan, Iowa), and decreased in the lower basin (near Warrenton, Missouri) since the 1900s (see discussion in Newman et al. 2014).

The freeze-free growing season within the LMR ranges from roughly 200 days near RM 670 to nearly 270 days near the Missouri River's confluence with the Mississippi River (Food and Agriculture Organization of the United Nations (FAO) 2007). Average annual precipitation ranges from roughly 32 inches in the upper reach of the study area to

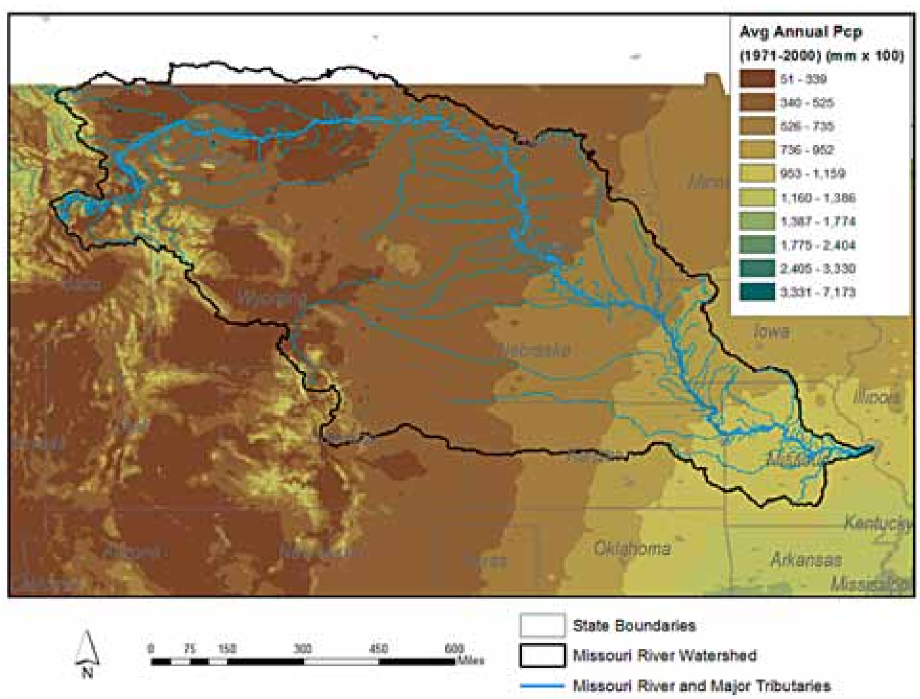


Figure 8. Average annual precipitation for the Missouri River watershed, 1971-2000 (from Hijmans et al. 2005).

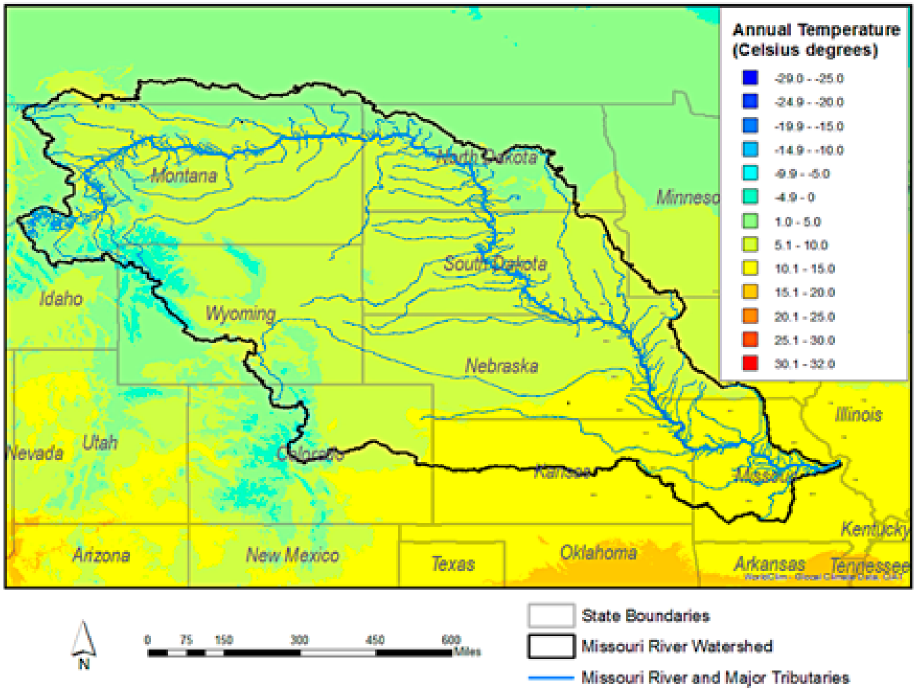


Figure 9. Average annual temperature for the Missouri River watershed, 1971-2000 (from Hijmans et al. 2005).

approximately 40 inches through portions of Central Missouri (Hesse et al. 1989a).

Long-term climate patterns in the LMR are evidenced from the periodicity of annual wet and dry cycles based on the Palmer Drought Severity Index (PDSI). This index represents moisture conditions based on monthly temperature and precipitation along with soil water holding capacity at a location (Palmer 1965). Across the study reach, wet/dry cycles regularly occur in about 10-year alternations on average, with extreme droughts occurring roughly every 15-20 years. Across all the assessed climate divisions, recent "dry" years generally have been less dry than in the past (prior to the 1960s) and occur slightly more often (10-15 year intervals), while "wet" cycles appear to have been slightly wetter compared to earlier records for most of the study reach, corresponding with record-high precipitation years (Appendices B2-7). These decadal wet/dry cycles are reflected in hydrographs of average annual streamflow data collected at the long-term USGS gaging stations.

The historic hydrology of the river included two seasonal pulses (see graphs in Appendices B2-7). The first pulse typically occurred in April and was caused by snowmelt in the Great Plains and the breakup of ice in the channels of the Missouri River and its tributaries. This first river rise tended to be brief, lasting about one to two weeks, and was relatively localized depending on regional climates. The second pulse typically was more dramatic, occurring in June and produced from snowmelt in the Rocky Mountains and spring increases in rainfall in the Great Plains and lower basin. The June rise lasted longer and frequently caused flooding in large parts of the river floodplain throughout the UMR (NRC 2002), while differences in spring and summer pulses are greatest in reaches downstream of Kansas City. In all reaches, late summer, fall and winter were characterized by declining river discharge and stages, which exposed channel shorelines and the many sandbars that were created from sediment deposition during the flood seasons.

River gage data collected prior to significant flow regulation beginning in 1954 indicate historic seasonal and annual flow dynamics in the LMR were highly variable, with conditions along the river reflecting flows from the upstream watershed and major local tributaries. This variability created a broad range of water levels during most years. Low flows in the late summer and fall exposed sand and gravel bars across its braided channels, while annual spring flooding events sustained floodplain wetlands, recharged surficial aquifers and facilitated continual channel formation and migration.

The seasonal dynamics of the Missouri River, coupled with long term variance in discharge amounts, and thus flood extent and duration, resulted in an almost continual erosion and deposition of the large sediments in the system. The quantity of sediment in the river clearly varied over season and years, and as an example it has been estimated that 11 billion cubic-feet of sediment were transported from the Missouri River into the Mississippi River at St. Charles, Missouri in 1879 (Laustrup and LeValley 1998). Average turbidity of the Mississippi River upstream of the Missouri's entry was about 300 parts/million while areas below the mouth of the Missouri were often near 1,800 parts/million (Platner 1946). Channel relocation was frequent as evidenced by river alignment maps from the Lewis and Clark Expedition in 1804 to the current time (see MS-3). Given the large variation in annual discharge of the river and its tributaries and the continual reworking of the river channel and its floodplain, the amount and distribution of seasonal flooding in the UMR was highly dynamic in relation to topography and elevation gradients, river and tributary channel migration and connectivity to floodplain depressions, and general form of floodplains at any given point in time (e.g., Galat et al. 1997).

As an example of the great variation in floodplain landform and flood recurrence potential, recent Land Capacity Potential Index (LCPI) models of flow-recurrence intervals demonstrate the significant within- and between-reach dynamics of inundation projection, or potential wetness (MS-7). The LCPI models intersect digital LiDAR elevation models for the LMR floodplain with sloping water-surface elevation planes derived from eight modeled discharges to create nine flow-recurrence interval classes from 0-2 to > 500-year recurrence. Methods and inference of these LCPI models are provided in Jacobson et al. 2007, 2011 and Chojnacki et al. 2012. It is worth noting that the recurrence interval mapping does not take into account whether or not water currently has an overland flow path to all floodplain areas because of levees, roads, ditches or other topographic/hydrological barriers or diversions and that mapped polygons may overestimate potential flooded areas at various recurrence intervals, even without existing levees. The models do, however, explicitly include USACE Flow Frequency Study levees for 100- and 500-year levee elevations (USACE 2004b) such that flows within levees are constricted, resulting in locally increased water-surface elevations. Based on the LCPI recurrence interval maps, clearly, certain reaches and subreach areas, such as the narrow floodplain in the Osage and Nodaway Reaches, the Grand and Chariton River confluence area, and the floodplain south of the Platte River confluence have large areas that typically flood on average every year while higher elevation floodplain north of Omaha, higher remnant Pleistocene terraces of the western Kansas Reach and on the north side of the Missouri-Mississippi Confluence, and alluvial fans on the edges of floodplains and entry points of smaller streams to the floodplain flooded less frequently, often at recurrence intervals of > 100 years.

The hydrogeology of the LMR is not well studied and appears complex (Granneman and Sharp 1979, Spooner 2001). The alluvial deposits that dominate the LMR floodplain contain highly permeable rocks, sand, and gravel that are interbedded with sand, silt, and clay. A thick silt-clay cap overlies sands and gravels of the floodplain's alluvial deposits across some portions of the LMR, which may limit surface-aquifer connections in some areas (Kelly 2001). The distribution of sediments causes exponential increase in hydraulic conductivity of groundwater with depth and both an upper and deeper groundwater system may exist in certain areas (Granneman and Sharp 1979). Regardless, the floodplain water tables in the LMR are clearly influenced by river stage, tributary flows, and local-regional precipitation. As an example, surface water in floodplain swales alternately fill or drain depending on river level at the Bob Brown and Franklin Island Conservation areas in Missouri (Missouri Department of Conservation, unpublished observations).

Ground water gradients generally trend away from the river valley walls toward the Missouri River and then downstream (Kelly and Blevins 1995). Water tables in specific locations depend on river stage, distance from the river, tributary stream character, and geometry of past and present river meander bends and bluff wall distance and alignment (Granneman and Sharp 1979, Foreman and Sharpe 1981). As an example, groundwater levels and inundation of shallow off-channel wetlands at Lisbon Bottom reflect both river level and infiltration and groundwater movement of Buster Branch near the east river valley wall (Jacobson et al. 1999). Groundwater fluctuations caused by river stage changes have been found to strongly control wetland water levels in other reaches of the LMR floodplain as well, while other wetlands are less-directly controlled by groundwater and have greater responses to surface water supplied through levee seeps or groundwater upwelling through alluvial deposits (Kelly 2001).

The drainage area upstream of Gavin's Point Dam (the most downstream main stem dam), constitutes approximately 53% of the total Missouri River Basin (Fig. 10) meaning that, to a large degree, these impoundments greatly influenced the hydrology of the LMR. However, despite regulation and channelization of the main stem and

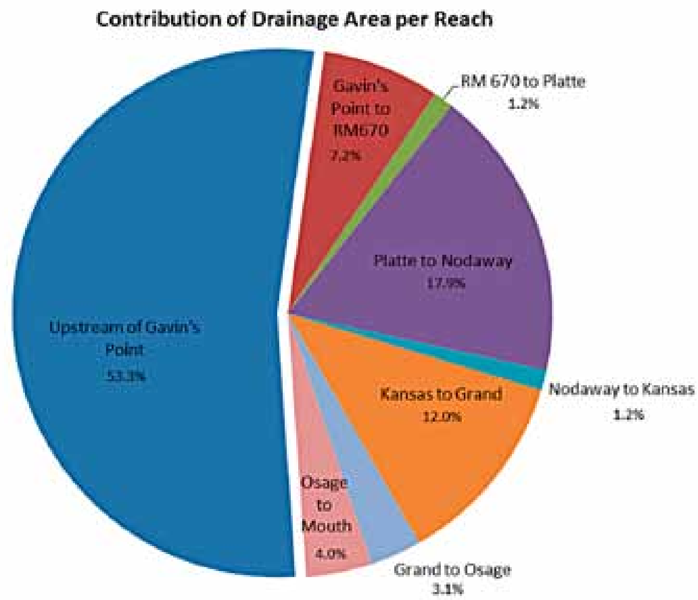


Figure 10. Contribution of drainage areas upstream of Gavins Point Dam and in LMR reaches to the entire Missouri River system (data from USACE 2004a).

tributaries, gage data from the lowest reaches of the LMR indicate that, at times, an aggregation of climatic conditions from the massive upstream watershed approaches some of the historic variance.

The influence of different portions of the watershed over Missouri River flows, and the ability of the Missouri River floodplain to attenuate flooding, is apparent when major flood peaks and average annual streamflow are compared among gage stations (Fig. 11). As construction of the main stem network neared completion in the spring of 1952 a rapid snow-melt across the upper, western Great Plains (USACE 2004b) led to the largest flood on record at gages from Bismarck, North Dakota to St. Joseph, Missouri, exceeding the next highest peaks on record at several gages by an astounding 200,000 cubic feet per second (cfs). In 1952, the peak streamflow at Yankton, South Dakota was 480,000 cfs but dissipated, presumably through floodplain storage, as it flowed downstream. In contrast, the mid-summer, central Midwest rain-induced flood event of 1993 was the highest historical peak streamflow at gages from Waverly, Missouri to Hermann, Missouri near the mouth. The peak of 750,000 cfs recorded at the Hermann gauge in 1993 is the highest flow in 170 years of record, while the 1952 peak attenuated to a "mere" 368,000 cfs by the time it reached Hermann.

PLANT AND ANIMAL COMMUNITIES

The LMR floodplain historically supported a diversity of plant and animal communities arrayed from the river channel to upland bluffs (Weaver 1960, Fig. 12). The previous discussion of the geomorphology and dynamics of the Missouri River channel and its floodplain demonstrate the complex and shifting landscape position of channel forms, islands and side chutes, sandbars, cutoff abandoned channels, point bar ridge-and-swale complexes, and floodplain terraces and bottoms (Schmudde 1961). Despite this regular frequent shifting of landforms, the LMR supported distinct vegetation communities in relation to soil type, elevation, topographic position, and hydroperiod. The following text provides relatively brief descriptions of the primary vegetation communities in the LMR. More complete descriptions of communities are provided in the classic botanical account of the Missouri River floodplain by Weaver (1960) and in other regional botanical publications (e.g., Weaver 1965, Nigh and Schroeder 2002, Steinauer and Rolfsmeier 2003, Nelson 2005). A comparison of various community classification systems related to geographic position and representative species is provided in the "cross-walk" Table 1. Descriptions of the biological attributes of the Missouri River channel features (channel, side channels and chutes, sandbars) are provided in several other sources (e.g., Sowards and Maxwell 1985; Hesse et al. 1982, 1989b).

The advance and retreat of the Wisconsin glacier, and subsequent climate changes in the Holocene Epoch, caused dramatic shifts in vegetation communities in the LMR. During full glacial periods, tundra and forest-tundra extended to about the present Missouri River channel (see previous geomorphology section and Delcourt et al. 1999). Boreal forest occupied the Mississippi River Valley and portions of the LMR to south of St. Louis during this time (Delcourt and Delcourt 1999). As continental warming occurred in the late glacial period, ice sheets retreated north and the spruce-larch boreal forest that occupied the LMR corridor during most of this period moved north and was replaced by mixed conifer hardwood forest by about 11,000 BP.

By about 9,500 BP, mesic deciduous oak forests became established in much of the southeastern part of the LMR. Prairie became widely established in the central and eastern plains as early as 10,000 BP and as climate continued to warm and dry during the Altithermal period 4-8,000 BP. The dry Pacific air allowed expansion of prairie east through the LMR and into Illinois between 3,000 and 5,500 BP. Often referred to as the "Prairie Peninsula," extensive mesic and some bottomland prairie occurred from the present Great Plains through the Missouri-Mississippi River Confluence area at this time (Transeau 1935). In the LMR, mesic upland prairie occupied higher elevation terraces and bluff slopes; wet-mesic and wet bottomland prairie covered extensive parts of lower floodplain bottoms and point bar surfaces; and deciduous forest occupied wetter areas along the Missouri River channel and chutes, in tributary valleys, and in some abandoned channel and depression areas in floodplains during this time. In the last 3,000 years, Arctic air flow increased across the central part of the Missouri River Basin and deciduous forest expanded from valleys and bluffs into many lower floodplain areas, mesic prairie retreated to the highest elevation terraces, and bottomland prairie retracted to higher elevation remnant glacial terraces and higher point-bar ridge/flat areas especially in the north part of the LMR (Delcourt and Delcourt 1981, Delcourt et al. 1999).

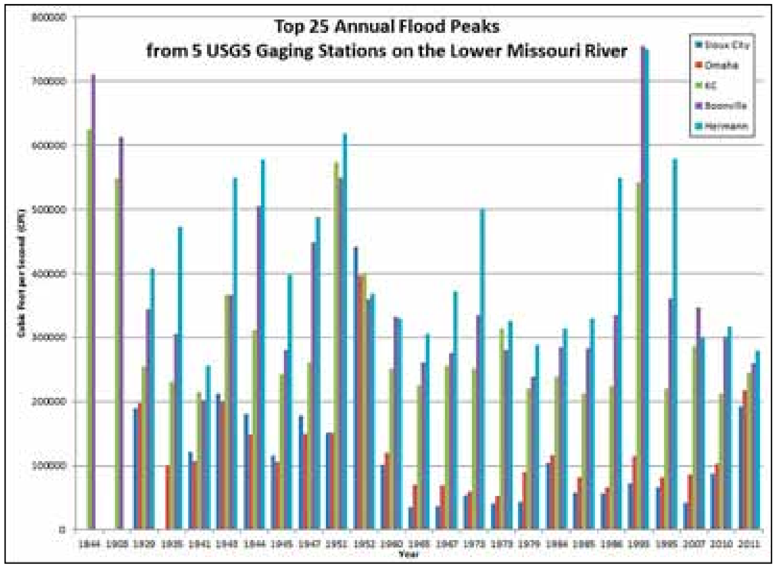


Figure 11. Top 25 annual flood peaks from five USGS gauge stations (USGS station numbers: 06486000, 06610000, 06893000, 06909000, and 06934500) in the LMR from 1844 to 2011 (USGS, 2012).

By the late 1700s to early 1800s, the presettlement LMR landscape occupied a central continental position between the great grassland biome to the west, conifer forests to the north, and deciduous forests to the east and south (Weaver and Fitzpatrick 1934, Weaver 1965, Nigh and Schroeder 2002). Post-glacial climate fluctuations caused the invasion and

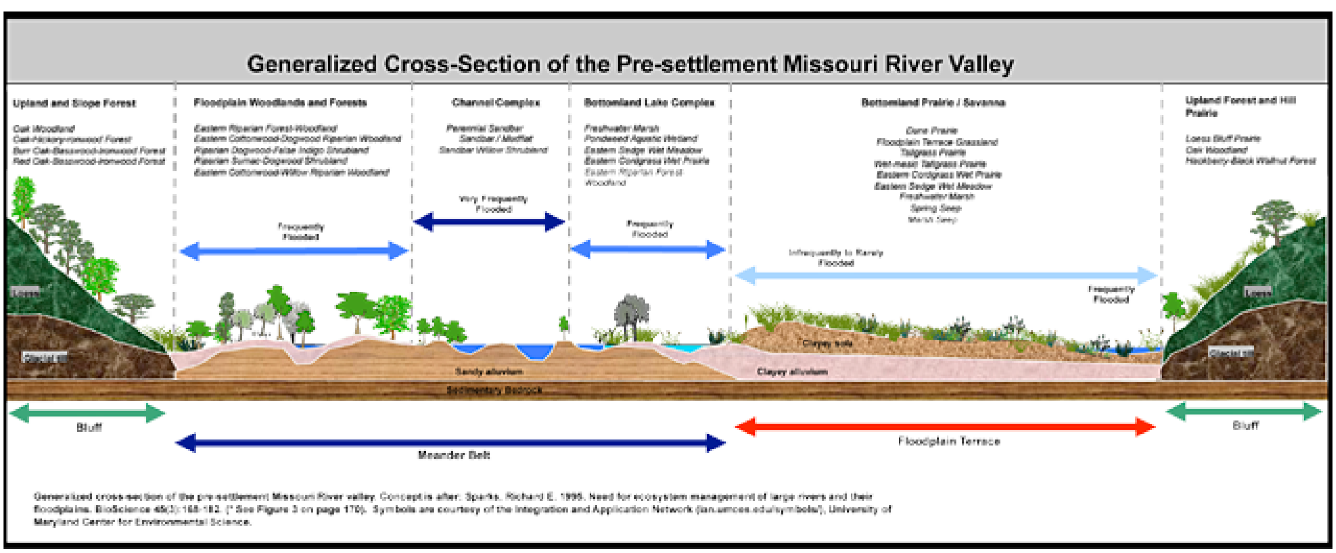


Figure 12. Generalized cross-section of vegetation communities in the pre-settlement Missouri River Valley (from Janke and Gilbert 2006).

Table 1. Cross-walk of various vegetation community classification systems related to geographic location, water regimes, and representative species for LMR habitats (from Janke and Gilbert 2006).

General Physiognomy	Plant Community Features	Representative Species	Cowardin Attribute	Flood Frequency	Predominant Water Sources	Soil Drainage Class	Geomorphic Surfaces
Channel Complex	Channel	NA	R2UBH	Continuous	Riverine	Water	Active River Channels
	Perennial Sandbar	*Salix exigua-Spartina pectinata*	PEMA/C,R2USC	Very Frequent	Riverine	Excessively Drained	Bar and Channel
	Sandbar/Mudflat	*Echinochloa crusgalli-Eragrostis pectinacea-Cyperus spp.*	PEMA/C,R2USC	Very Frequent	Riverine	Poorly Drained-Well Drained	Bar and Channel
Oxbow Lake	Freshwater Marsh	*Typha latifolia-Schoenoplectus spp-Sparganium eurycarpum*	PEMF	Frequent	Riverine - Groundwater	Very Poorly Drained	Abandoned Channels/Overflow Channels
	Pondweed Aquatic Wetland	*Ceratophyllum demersum-Najas guadalupensis-Potamogeton spp.*	PABG,L2ABG	Frequent	Riverine - Groundwater	Very Poorly drained - Water feature	Abandoned Channels/Overflow Channels
Backswamp	Freshwater Marsh	*Typha latifolia-Schoenoplectus spp-Sagittaria spp.*	PEMF	Occasional	Precipitation-Runoff-Riverine	Very Poorly Drained - Poorly Drained	Backswamp
	Pondweed Aquatic Wetland	*Ceratophyllum demersum-Potamogeton spp.-Zannichellia palustris*	PABG	Occasional	Precipitation-Runoff-Riverine	Very Poorly drained - Poorly Drained	Backswamp
	Eastern Sedge Wet Meadow	*Carex cristatella-C. vulpinoidea-Scirpus atrovirens*	PEMC/F	Frequent - Occasional	Precipitation-Runoff-Riverine	Poorly Drained	Backswamp
Floodplain Forest and Woodlands	Eastern Cottonwood-Willow Riparian Woodland	*Populus deltoides-Salix amygdaloides*	PSSA/C	Frequent	Riverine	Moderately Well Drained	Point bar ridges
	Sandbar Willow Shrubland	*Salix exigua var. sericans*	PSSA/C	Frequent	Riverine	Moderately Well Drained	Point bar swales and Tributary riparian zones
Bottomland Hardwood Forest	Eastern Riparian Forest-Woodland	*Fraxinus pennsylvanica-Ulmus americana-Celtis occidentalis*	PFOA/J	Rare	Precipitation	Somewhat Poorly Drained-Well Drained	Point bar ridges and floodplain depressions
	Eastern Cottonwood-Dogwood Riparian Woodland	*Populus deltoides-Cornus drummondii*	PFOA/J	Rare	Precipitation	Somewhat Poorly Drained-Well Drained	Level Floodplain,Terraces
	Riparian Dogwood-False Indigo Shrubland	*Amorpha fruticosa-Cornus drummondii-C. sericea*	PSSJ	Rare	Precipitation	Somewhat Poorly Drained-Well Drained	Natural Levee,Terraces
	Riparian Sumac-Dogwood Shrubland	*Rhus glabra-Cornus drummondii*	Upland	Rare	Precipitation	Somewhat Poorly Drained-Well Drained	Level Floodplain,Terraces
Bottomland Prairie/Savanna	Missouri River Valley Dune Prairie	*Calamovilfa longifolia -Elymus canadensis-Sporobolus cryptandrus*	Upland	Very Rare	Precipitation	Well Drained	Eolian Dunes
	Missouri River Floodplain Terrace Grassland	*Elymus canadensis-Panicum virgatum-Carex cristatella*	Upland	Rare	Precipitation	Well Drained	Point bar surfaces
	Tallgrass Prairie	*Andropogon gerardii-Hesperostipa spartea-Sporobolus heterolepis*	Upland	Rare	Precipitation	Moderately Well Drained-Well Drained	Floodplain Terraces (Holocene)
	Wet-mesic Tallgrass Prairie	*Andropogon gerardii-Sorghastrum nutans-Carex missouriensis*	Upland/PEMA	Occasional - Rare	Precipitation-Groundwater	Poorly Drained-Somewhat Poorly Drained	Point bar swales and floodplain terraces
	Eastern Cordgrass Wet Prairie	*Spartina pectinata*	PEMA	Frequent - Occasional	Precipitation-Groundwater-Riverine	Poorly Drained	Point bar swales and terrace depressions
	Eastern Sedge Wet Meadow	*Carex cristatella-C. vulpinoidea-Scirpus atrovirens*	PEMC/F	Frequent - Occasional	Precipitation-Groundwater-Riverine	Very Poorly Drained	Point bar swales, terrace depressions, backswamp
	Spring Seep	*Typha latifolia-Equisetum hyemale-Carex hystericina*	PEMB	Very Rare	Groundwater	Very Poorly Drained	Interfluve /Toe Slope
Upland and Slope Forest	Oak-Hickory-Ironwood Forest	*Quercus alba (Quercus velutina) - Carya ovata-Ostrya virginiana*	Upland	None	Precipitation	Well Drained	Bluffs-Middle slopes
	Bur Oak-Basswood-Ironwood Forest	*Tilia americana – (Quercus macrocarpa) / Ostrya virginiana*	Upland	None	Precipitation	Well Drained	Bluffs-Middle slopes
	Red Oak-Basswood-Ironwood Forest	*Quercus rubra-Tilia americana -Ostrya virginiana*	Upland		Precipitation	Well Drained	Middle to lower Slopes of Bluffs
Upland Forest and Hill Prairie	Loess Bluff Prairie	*Schizachyrium scoparium-Bouteloua curtipendula-Bouteloua hirsuta*	Upland	None	Precipitation	Excessively Drained	Hilltop,upper slopes of bluffs
	Oak Woodland	*Quercus macrocarpa-Andropogon gerardii - Hesperostipa spartea*	Upland	None	Precipitation	Excessively Drained	Hilltop,upper slopes of bluffs
	Lowland Hackberry-Black Walnut Forest	*Celtis occidentalis-Gymnocladus dioica-Juglans nigra.*	Upland	None	Precipitation	Well Drained	Alluvial Fans, Colluvial Apron Terrace Edges

retreat of many different plant and animal associations and caused a rich biological diversity in the region. The heterogeneity of geomorphic surfaces, soils, and topography in the LMR created diverse and highly interspersed vegetation communities distributed across elevation and hydrological gradients (Fig. 11). Major natural communities/habitat types that historically were, and still are, present in the LMR included: 1) the main channel and islands of the Missouri River and their major tributaries, 2) river "chutes" and "side channels", 3) abandoned channel bottomland lakes and larger sloughs, 4) riverfront forest, 5) floodplain forest, 6) slope forest, 7) bottomland marshes, 8) wet bottomland prairie, 9) wet-mesic prairie, 10) mesic prairie, and 11) mixed woodland-prairie savanna. Lists of fauna and flora along with scientific names of species in these habitats are provided in Weaver (1960, 1965); Terpening (1974); Galatowitsch and McAdams (1994); Nigh and Schroeder (2002); Steinauer and Rolfsmeier 2003; Nelson (2005); and others.

Channels, Islands, and Bars - The main channel of the Missouri River and its major tributaries contain open water with little or no plant communities other than phytoplankton and algae. During low river levels in late summer and early fall, some river chutes and side channels historically became disconnected from main channel flows and had stagnant water that supported sparse herbaceous "moist-soil" plants that germinate on exposed mud flats (Weaver 1960). During high river flows chutes and side channels historically were connected with the main channel and scouring action of river flows prevented establishment of rooted plants in these habitats. The extent and duration of river connectivity was the primary ecological process that controlled nutrient inputs and exports, primary and secondary productivity, and animal use of chutes and side channels. A wide variety of fish historically were, and still are, present in the Missouri River and tributary rivers and their side channels (e.g., Pflieger 1975, Hesse et al. 1989b, Galat et al. 2005), and these habitats also historically were used by many amphibians, a few aquatic mammals, and some water and shorebirds (Smith 1996).

Historically, few large more-permanent "islands" occurred within the Missouri River or its lower tributary channels, but numerous constantly shifting sandbars were common on the edges of channels, especially on the downward side of major bends, and in braided river areas (see discussion in Holbrook 1995, 1996, Kashouh 2012 and maps in Appendix MS-3). When islands formed, they were separated from the floodplain by narrow, often highly sedimented, older side channels. During dry periods these "islands" became extensions of terrestrial floodplain surfaces. Vegetation on islands and bars depends on size, configuration, and connectivity to banks (see Hesse 1996). The degree and duration of flooding and connectivity to either the river or floodplain control ecological attributes and animal use of islands and river bars. Most islands and bars historically were 1-4 feet below adjoining floodplain elevations and were overtopped during annual high flow periods. During floods, river bars often were extensively scoured or destroyed, and new bars were created in other locations. Vegetation on bars was mostly pioneering plants that germinated on newly deposited alluvium (Weaver 1960). Annual herbaceous plants and seedlings of cottonwood, sycamore, and willow were the most common plants.

Bottomland Lakes - Bottomland lakes historically were present in many locations in the LMR where river meander cutoffs occurred (Appendices MS-2, MS-3). Today, many of these bottomland lakes remain as remnants of former channel changes ranging from Marais Temps Clair at the Missouri-Mississippi River Confluence to DeSoto Lake north of Omaha. The location, age, and size of bottomland lakes determine depth, slopes, and consequently composition and distribution of vegetation communities. Many bottomland lakes in the northern LMR historically were surrounded, or partly adjoined, by prairie communities and essentially were large "prairie marshes" with little woody vegetation on their edges (see descriptions by Lewis and Clark in Moulton 1988). The sparse woody vegetation along prairie-type lakes was mostly scattered willow and shrubs such as buttonbush (Weaver 1960). Robust emergent vegetation such as cattail and river bulrush dominated plant composition along the edges of these lakes. Other bottomland lakes were surrounded at least in part by forest habitats. These lakes usually contained a narrow band of shrub/scrub (S/S) vegetation along their edges. S/S communities represent the transition area from more herbaceous and emergent vegetation in the aquatic part of bottomland lakes to higher floodplain surfaces that support trees. S/S habitats typically are flooded a few inches to 2-3 feet deep for extended periods of each year except in extremely dry periods. S/S habitats in the LMR are dominated by buttonbush and willow. Often natural levees were present along the edges of historic bottomland lakes and these areas supported riverfront or floodplain forest species assemblages. In most lakes, the cutoff ends contain riverfront forest species such as willow, cottonwood, and sycamore that germinate on coarse-grain materials that had "plugged" the old abandoned channel (Nelson 2005, Heitmeyer et al. 2011).

Most newer and deeper bottomland lakes in the LMR such as those encountered by Lewis and Clark; and that remain today such as Big Lake, Lewis and Clark Lake, Dalton Cutoff, and others tend to have central areas of permanent "open water" that contain abundant aquatic "submergent" and "floating-leaved" vascular species such as pondweeds, coontail, water milfoil, American lotus, spatterdock, and duckweeds (i.e., various descriptions of lake vegetation in Lewis' notes from Moulton 1988, and see Castaner and LaPlante 1992, Blevins 2004). The edges of these lakes historically dried for short periods during summer and contained persistent emergent and seasonal herbaceous vegetation (often termed "moist-soil" vegetation, see e.g., Fredrickson and Taylor 1982). Persistent emergent vegetation (PEM) in these bottomland lakes typically includes arrowhead, cattail, rushes, river bulrush, sedges, and spikerush. Seasonal herbaceous vegetation is dominated by smartweeds, millet, panic grasses, sprangletop, sedges, spikerush, beggarticks, and many other perennial and annual "moist-soil" species. The distribution of PEM and herbaceous communities in bottomland lakes depends on length and frequency of summer drying seasonally and among years (sees previous hydrology section about long-term dynamics of flood events and intervening dry periods). In drier periods, herbaceous communities expanded to cover wide bands along the edges of bottomland lakes, while in wetter periods herbaceous plants were confined to narrow bands along the edges of deeper open water.

Bottomland lakes, both "prairie-marsh" and "forest-edge" types, historically supported a high diversity of animal species. Historically, fish moved into these lakes for foraging and spawning when they became connected with the Missouri and tributary rivers during flood events (Galat et al. 1996, 2005). Many fish subsequently moved back into the main channel when flood water receded or after they spawned or fattened during flood events; some fish remained to populate the deeper lakes. Bottomland lakes also support high density and diversity of amphibian and reptile species and some species, such as turtles, move into and out of these lakes similar to fish (Smith 1996). Aquatic mammals also regularly use bottomland lakes and more terrestrial mammals travel in and out of these areas for seasonal foraging, breeding, and escape cover during dry periods. Bird diversity in the historic bottomland lakes in the LMR was, and still is, high, and extremely high densities of waterfowl, rail, shorebirds, and wading birds use these habitats for foraging, nesting, and resting sites (Smith 1996, Raedeke et al. 2003).

Riverfront Forest - Riverfront forest (also called "river-edge forest" in some older botanical literature) historically was present in extensive areas of the LMR on island and bar surfaces, point bar areas near active channels, along the edges of some abandoned channels, and areas of coarse sediment sand and gravel deposition (Pound and Clement 1900, Hus 1908, Hansen 1918, Aikman 1926, Weaver 1960, Harlan 2002, Nigh and Schroeder 2002). These geomorphic surfaces contain recently accreted lands and are sites where river flows actively scoured and deposited silt, sand, gravel, and some organic debris. Soils under riverfront forest communities, especially on chute and bar surfaces, are young, annually overtopped by flood waters, highly drained, influenced by groundwater dynamics as the Missouri River and tributaries rise and fall, and often contain thin veneers of silt. Riverfront forest habitat is dominated by early succession tree species and varies from water tolerant species such as willow and silver maple in low elevations and swales to intermediate water tolerant species such as American elm, green ash, cottonwood, and sycamore on ridges (Weaver 1960, Nelson 2005). A few oak trees occasionally are present in higher elevations in riverfront forest areas, but these species have high mortality during extended flood events and any historical oak/pecan patches probably were small and scattered (Weaver 1960). Shrubs and herbaceous vegetation in riverfront forests are sparse near the edge of rivers but dense tangles of vines, shrubs, and herbaceous vegetation often are present on higher elevations away from the river where alluvial silts were deposited. The dynamic scouring and deposition in island and bar areas limited the tenure of many woody species except on the highest elevation ridges where species such as cottonwood and sycamore often became large mature stands (e.g., Turner 1936, Weaver 1960).

Riverfront forests are used by many animal species, especially as seasonal travel corridors and foraging sites. Many bird species nest in riverfront forests, usually in higher elevation areas where larger, older, trees occur (Knutson et al. 1996). Arthropod numbers typically are high in riverfront forests during spring and summer and these habitats also contain large quantities of soft mast that was consumed by many bird and mammal species (e.g., Knutson et al. 1996). Few hard mast trees historically occurred in riverfront forests, but occasional "clumps" of oak may have provided locally abundant nuts. The very highest elevations in chute and bar areas provide at least some temporal refuge to many ground-dwelling species during flood events (Heitmeyer et al. 2005).

Currently, more remnant riverfront forest stands remain in the LMR compared to any other historical community type. This community typically occurs on islands and bars (e.g., Howell and Pelican islands), side chute areas (Lisbon Bottoms), edges of abandoned channel cutoffs (Dalton Cutoff), river edges (most riparian areas along the current river channel), and sandy soils in low elevations of floodplains (Berger Bend Unit of Big Muddy NFWR).

Floodplain Forest and Woodland-Savanna - Floodplain forest communities historically covered many higher elevation LMR "second bottom" floodplain areas along Holocene channel belt point bar surfaces and along tributary streams (Pound and Clement 1900, Hus 1908, Hansen 1918, Telford 1927, Aikman 1926, Weaver 1960, Nelson 2005). This forest type represents a transition zone from early succession riverfront forest located on annually flooded coarse sediments next to river channels to rarely flooded upland "slope-type" forests near river valley bluffs. The community classification descriptor "bottomland" is often used to categorize the broader floodplain forest community, which can be further divided into "wet" and "wet-mesic" floodplain "woodland" and "forest" based on frequency of flooding and density coverage of trees (Nelson 2005, Heitmeyer and Nelson 2014). In this report we use the general term "floodplain forest" to describe this community type range, recognizing that more subtle subdivision of the community related to degree of flood inundation and tree density occurs. Floodplain forest habitats typically develop on mixed silt loam soils where older point bar "ridge-and-swale" topography occurs. Most of these older point bar surfaces are at or above the 2-5 year flood frequency zone (Appendix MS-7). Floodplain forests in the LMR contain a diverse suite of species especially American elm, green ash, sweetgum, hackberry, and box elder but include many other species depending on elevation and soil type. Higher elevation ridges and older remnant natural levees often contain scattered pecan, pin oak, bur oak, honey locust, and scattered hickory. Low elevation swales within floodplain forests contained a mix of more water tolerant species that includes willow, cottonwood, maple, and sycamore on coarser soil sediments to oak, ash, sweetgum, and pecan in river meander belt point bar swales that have veneers of silt and/or clay. Generally, species composition and diversity in floodplain forests are highest in southern and eastern parts of the LMR and lowest in northern reaches, especially in the Little Sioux Reach where floodplain forest typically contains mainly box elder, American elm, hackberry, bur oak and interspersed cottonwood and sycamore (Weaver 1960).

Larger, deeper, swales within floodplain forest patches often contain surface water for extended periods of the year and support gradients of vegetation similar to forest-edge bottomland lakes but at a smaller spatial scale. Dense understory layers of coralberry, wolfberry, elder, indigobush, smooth sumac, gooseberry, frost grape, and poison ivy were present in many LMR floodplain forests (Weaver 1960). Early explorers often commented on the "impenetrable" nature of these floodplain forests (e.g., Bradbury 1809, Collot 1826, Moulton 1988). Herbaceous cover tends to be more extensive in higher elevations of floodplain forests and includes many herbs such as Virginia snakeroot, smooth ruellia, honewart, elephant's foot, fleabane, and rough bedstraw (Nelson 2005).

Floodplain forest areas next to historic or existing prairies often have less dense stands of trees and become "woodlands" or scattered tree type "savanna" (Aikman 1926, Weaver 1960, Nelson 2005). In these areas wet-mesic woodlands historically occupied broad transition zones in LMR floodplains between prairies and true forest communities along stream and river corridors (Nigh and Schroeder 2002, Nelson 2005). Trees in woodland habitats often are open grown (orchard like) and take on a savanna-like interspersion with tall bottomland prairie grasses, sedges, and herbaceous plants covering most of the ground cover. Slopes in LMR floodplain woodlands are nearly level and soils are often poorly drained. Seasonal flooding occurs from both river backwater and local runoff sources especially in fall, winter, and spring. Most flooding is shallow, but can last for a month or so in higher water conditions. The combination of seasonal flooding and regular fire historically had a direct influence on the patterns of floodplain woodland distribution. During dry years fire burned into the woodlands from adjacent prairies, while shallow backwater flooding of 2-5 year recurrence was important to constrain fires and to sustain dominant woody plants. Dominant trees in LMR woodlands were pin oak, bur oak, pecan , cottonwood, and some shellbark hickory in higher areas (Weaver 1960, Nelson 2005, Heitmeyer et al. 2011). Shrubs included buttonbush and herbaceous cover contained prairie cordgrass, sedges, rice cutgrass, fowl manna grass, bluejoint, and numerous sedges.

Generally, the distribution of prairies vs. forest/woodland in the LMR was determined by the dynamic "line" of where floodwater ranged toward higher elevations in floodplains vs. the "line" where fires originating from uplands and higher elevations moved into the wetter lowlands (Weaver and Fitzpatrick 1934, Nelson 2005, Heitmeyer 2008, Thogmartin et al. 2009). Transition areas between bottomland prairie and forest in the LMR floodplain, especially on terraces and tributary fans probably historically contained oak-dominated savanna (Weaver 1960). Historically, bottomland prairie and savanna vegetation was partly maintained by seasonal burning started by natural events (e.g., lightning strikes) and native people and also by herbivory from elk, bison, deer, and many rodents (e.g., Nelson 2005). This herbivory cropped and recycled prairie vegetation and also browsed invading woody shrubs and plants. Almost no true savanna remains in the LMR, although several areas have a more open "woodland" character such as at the Qumessourit Natural Area (NA) at Van Meter State Park in Saline County, Missouri and pecan-oak grove areas adjacent to Dalton Cutoff.

The floral and elevation diversity of floodplain forests, woodlands, and savanna historically provided abundant resources to many animal species. Many mammals, including rodents, ungulates, and canids are present as are amphibians and reptiles. Bird abundance in floodplain forests is high and includes species that breed, winter, and migrate through the area (Knutson et al. 1996). During flood events, floodplain forests often become refuge for species that more regularly use lower elevation riverfront forest. During larger floods, fish move into floodplain forests for spawning and foraging.

Few large tracts of floodplain forest remain in the LMR. Most remnant tracts are inclusions of high elevation ridges within otherwise riverfront forest areas (e.g., Cora Island), inside bends of point bars near abandoned channel lakes (sites on Weston Bend State Park and at Wilson Island State Park prior to the 2011 flood), fragmented patches on the edges of floodplain terraces (areas north and east of Dalton Cutoff and on Van Meter State Park), and regenerating forest on higher elevation long bottom areas (Overton Bottoms, Franklin Island, LaBenite Park).

Slope Forest - Slope forests historically occupied alluvial-colluvial fans along the edges of the LMR floodplain, mostly where upland bluff sediments have eroded onto the floodplain margins (Hansen 1918, Costello 1931, Weaver 1960, Nelson 2005). These slope forests are especially associated with erosional fans off of loess bluff forest in the northern parts of the LMR. Examples of these areas include small fans associated with the Riverbreaks, Monkey Mountain, and Brickyard Hill Conservation Areas (CA) in northwest Missouri, Isley Park Woods, Hidden Valley and Maple Woods NAs in Clay County, Missouri; the Schnabel Woods NA in Boone County, Missouri; and Waubonsie State Park areas in southwest Iowa. Slope forests in the LMR contain a unique mix of trees representing both upland and bottomland communities that occur in higher (upland) and lower (floodplain) elevations adjacent to the alluvial fan or terrace. Some authors refer to this habitat as the "shatter zone" between upland and valley floor plant associations (Gregg 1975). The diverse tree species present in slope forests included hickory, hackberry, white oak, bur oak, red oak, linden, walnut, ash, mulberry, maple, box elder, paw paw, hawthorn, persimmon, green ash, honey locust, Kentucky coffeetree, and slippery elm (Weaver 1960, and see GLO maps in Appendix MS-10). Many other woody species are present in the understory and as occasional canopy trees.

Slope forests were not historically flooded except during extreme Missouri River flood events. Even during extreme floods, only the bottom of slopes would have been inundated. Rather, most water flowed off the slopes in a wide overland sheetflow manner and only minor drainages originated from the slopes. Slopes often are bounded by slightly larger drainages that originated in bluffs and uplands. Some slope areas in many northern parts of the LMR and in the eastern Kansas Reach historically were bounded by prairie (Appendix MS-10). In these prairie-forest transition sites, savanna was present as narrow bands at the bottom of the slopes and probably was maintained by occasional fire. Fires in these areas may have originated in either the floodplain bottoms or uplands and likely contributed to sustaining the diverse mix of woody, herbaceous, and grass species.

Many animals use slope forests and these sites also were preferred sites for Native American settlements (e.g., Bauxer 1978). These sites contained rich floral communities, multiple food types, and relief from periodic flooding and bothersome insects in the lowlands. These areas also provided a natural sloping movement corridor from bottomland to uplands and bluffs.

Mesic and Wet-Mesic Prairie - Remnant glacial till terraces and higher elevation second bottom flats that are subset within or are on the edges of LMR floodplains historically were covered with wet-mesic prairie; a few very high elevation terraces sites contained drier mesic "tallgrass" prairie (Pound and Clement 1900, Weaver and Fitzpatrick 1934, Weaver 1960, Schroeder 1982, Nigh and Schroeder 2002). Soils on terraces that supported prairie are mostly silt loam loess and glacial till-derived, moderately well drained, very deep (>60 inches), high fertility, and strongly acid to neutral soil reaction (5.1-7.3 pH) (Weaver and Fitzpatrick 1934, Weaver 1960, Schroeder 1982, Nigh and Schroeder 2002). Small relict glacial terraces within the floodplain, such as in the Grand River confluence area, often have rather marked (8-15%) side slopes. Historically, most wet-mesic prairie terraces in the LMR were infrequently flooded (> 5-year recurrence). Local precipitation caused sheetwater runoff across terraces and some surface water infiltrated terrace soils. Wet-mesic terrace prairies typically have slightly more sheetwater flooding than mesic sites and contain some plant species slightly more adapted to extended soil saturation such as prairie cordgrass (Nelson 2005). Fire undoubtedly was a dominant ecological disturbance for the terrace prairies prior to European settlement. Bison and elk were present in these sites until the late 1800s (Wells 1948) and they apparently had considerable influence on structure and composition of communities through heavy grazing. Dominant plants on mesic terrace prairies included big bluestem, little bluestem, Indian grass, blue grama, switchgrass, Canada wild rye, hairy grama, large beard tongue, soapweed, plains muhly grass, and rosinweed (Weaver 1960). Scattered shrubs included sumac, dogwood, prickly ash, and wild plum. Forbs included oxeye, saw-tooth sunflower, Jerusalem artichoke, and various species of goldenrod and aster. Prairie cordgrass, bluejoint, and mixed sedges were more dominant in wet-mesic terrace prairies and other species included eastern gama grass, rice cutgrass, fowl mannagrass, Virginia wildrye, American sloughgrass, northern reedgrass, bluejoint, stout wood reed, and shortawn foxtail . Common shrubs in wet-mesic prairies included American hazelnut, wild plum, and prairie willow. Herbaceous layers included prairie dropseed, eastern gama grass, culver's clover, and many others. The rich diversity of plant species covered the entire terrace prairie community and grass and forb heights ranged from 5-7 feet (Weaver 1960).

The only remnant mesic and wet-mesic prairie patches that remain in the LMR are small areas, usually on the edge of the floodplain in state or federally protected conservation lands. For example, the Star School Hill Prairie NA south of Hamburg represents a mesic type prairie that formerly merged with the LMR floodplain (Missouri Natural Areas Committee 1996). Other small sites include those on Iowa Department of Natural Resources (IDNR) lands, slope areas north of Blair, Nebraska, some road edge areas in Carroll and Chariton counties, Missouri, sites north of Squaw Creek NWR near Craig, Missouri and very small scattered patches in St. Charles County, Missouri.

Wet Bottomland Prairie - Wet bottomland prairies historically were present throughout the alluvial deposits of the LMR mostly on silty clay soils with 0-2 percent slopes (Weaver and Fitzpatrick 1934, Weaver 1960, Schroeder 1982, Nigh and Schroeder 2002, Nelson 2005). These floodplain prairies historically had short duration flooding from sheetwater flow that drained from terraces onto the floodplain and from occasional backwater flooding of the Missouri River and its major tributaries (e.g., Henszey et al. 2004). Plant communities in wet bottomland prairies ranged from perennial marsh-type vegetation in low elevations to more wet-mesic-type terrace grasses and forbs in higher elevations on the edge of the floodplain (Weaver 1960, Nelson 2005). Some surface flooding occurred almost annually in low elevation prairies, but surface inundation was likely strongly seasonal, with most inundation occurring in spring and early summer. Wet bottomland prairies were present on poorly drained deep soils, often with silty clay texture, and had seasonally high water tables with standing water present during spring and winter or after heavy rains. Dominant plants in these low elevation wet prairies include prairie cordgrass, smartweeds, spikerush, buttonbush, false indigo, swamp milkweed, rice cutgrass, river bulrush and numerous sedges and rushes (Weaver 1960). The best examples of wet bottomland prairie that remain in the LMR are areas in Squaw Creek NWR and USDA Wetland Reserve Program (WRP) lands southeast of Dalton Cutoff.

Floodplain Marshes - Floodplain marshes, often termed wet bottomland prairie-marsh (Nelson 2005), historically were present in deeper swales that had more permanent water regimes within LMR floodplains. Plant assemblages in these marshes were similar to those in abandoned channel bottomland lakes (described above) and included diverse herbaceous moist-soil and PEM species along with submergent aquatic vegetation in deeper areas (Castaner and LaPlante 1992). The extent and distribution of marsh-type species varied markedly among wet and dry periods of longer term climate and flooding frequency periods. During dry periods, bottomland marshes likely dried and species shifted more toward wet mesic and/or wet bottomland prairie types, while during wet periods the marshes more closely resembled open water-vegetation interspersion associated with abandoned channel lake marshes (Weaver 1960). Several floodplain marshes remain in the LMR, mostly in managed conservation land holdings. Examples include floodplain depressions and remnant swale areas at Little Bean Marsh, Cooley Lake, and Marais Temps Clair

CAs; Squaw Creek and DeSoto NWRs; IDNR lands; Teteseau Lake on Grand Pass CA; and several WRP lands in the Wakenda and Dalton Cutoff Bottoms in the east Kansas and west Grand Reaches.

DISTRIBUTION AND EXTENT OF PRESETTLEMENT HABITATS

The exact distribution of vegetation communities (habitat types) in the LMR prior to significant European settlement in the mid-1800s is not known. Additionally, the extent and distribution of communities in the LMR undoubtedly was highly dynamic and changed frequently as river channels migrated and as flood events rearranged sediments and entire landform topography. Consequently, any attempt to map presettlement community distribution in the LMR would only be a narrow "window" of conditions at a specific time that likely changed soon thereafter.

Given the above caveat of community distribution dynamics, many sources of information about the geography of major vegetation communities are available for the LMR and they include historic cartography, botanical data and accounts, and general descriptions of landscapes from early explorers and naturalists. These accounts start with the descriptions of landscapes provided by the Lewis and Clark expedition in 1804 (Gass 1958, Biddle 1962, Coues 1965, Moulton 1988, Phillips 2003) and also include later General Land Office (GLO) survey notes from 1817 to 1840 (Harlan 2002, 2010), botanical records and observations from the 1800s and early 1900s (e.g., Brackenridge 1814, Bradbury 1817, Audubon 1843, Missouri River Commission 1895, Pound and Clement 1900, Hansen 1918, Trudeau 1921, Larpenteur 1933, Aikman 1926, Costello 1931, Weaver and Fitzpatrick 1934, Weaver 1960, Nichols 1969), plat maps, land cover maps prepared by the Missouri River Commission in 1879 and 1894 (Missouri River Commission 1879, 1895, Appendices MS-8, MS-9), 1928 aerial photographs (Fig. 13), and early settler accounts (e.g., Hoy 1872).

A previous attempt to map potential historical vegetation distribution was based on GLO survey notes in Missouri and Iowa, and was a start to understanding community relationships in the LMR (Harlan 2002-2010; Appendix MS-10). Caveats of GLO notes (e.g., Hutchinson 1988, Brugam and Patterson 1996, Nelson 1997, Black and Abrams 2001) prevent precise understanding of community distribution and relationships with geomorphic attributes such as soils, geomorphic surface, flood frequency, and elevation. Nonetheless, the GLO-based vegetation maps provide excellent data on major community divisions such as prairie vs. forest and identify tree species and relative density at sections corners, and in some cases mid-points between surveyed corners. These tree species records provide important insight about the relative abundance and distribution of riverfront vs. floodplain forest assemblages within LMR reaches. More recently, efforts have been made to expand GLO analyses to include community relationships to contemporary soil, geomorphic, and elevation surfaces for areas in Missouri including the LMR (see maps prepared by Tim Nigh and Frank Nelson in Heitmeyer and Nelson 2014,discussion of ecological site description (ESD) methods by Nigh in Heitmeyer et al. 2011, Appendix MS-11). These historical vegetation maps, or ESDs, rely heavily on soil data and mapping, which reflects the time and level of detail of contemporary soil surveys and current landscape features such as current location of oxbows, river channels, man-made and altered areas such as cities, and strip mines. Soil orders also may lack correspondence with wetness classes, which can limit understanding of community relationships (Jacobson et al. 2011:305-306). Consequently the ESD maps, while more inclusive of HGM data such as soils than the older GLO-based maps, likely do not accurately reflect exact community distribution during presettlement periods where major changes in river channel form and location occurred, where man-made changes to landscapes have occurred, and where floodplain landscape topography has been altered either by sediment dynamics or by man.

Despite the caveats of both the GLO and ESD maps (Appendices MS-9, MS-10), they both provide wonderful insights into general patterns of historical natural community distribution in the LMR. Based on the above information about communities and some insight of their historical distribution, we prepared a matrix of HGM land attributes associated with historical LMR communities (Table 2). This matrix essentially describes relationships of communities with geomorphology surfaces, soils, topography, and hydrological regime. The following community generalities and consistencies for historical LMR reaches are provided below.

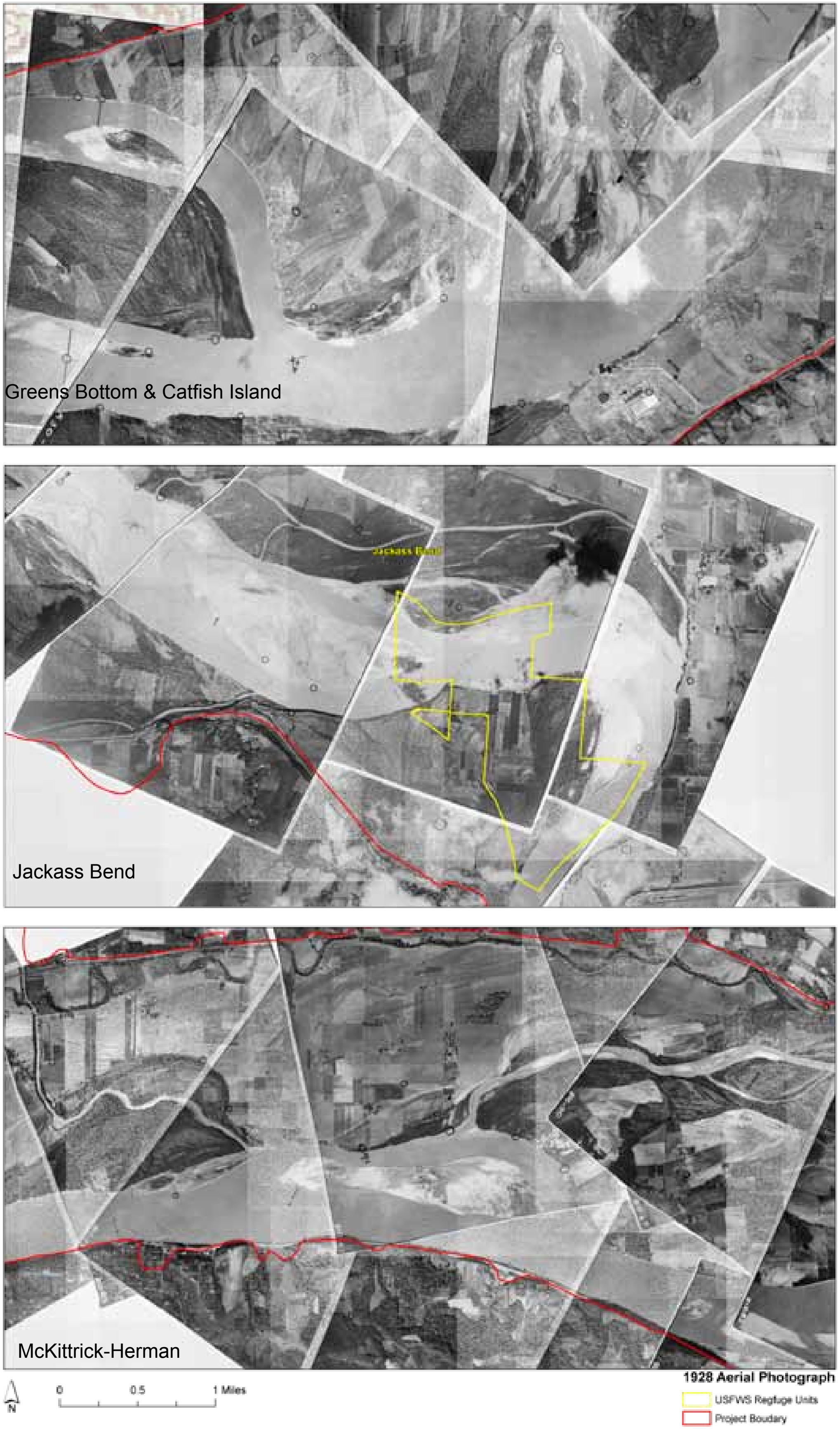


Figure 13. Old historical aerial photographs from 1928 of select locations in the LMR (from USACE).

Table 2. Hydrogeomorphic (HGM) matrix of historic distribution of vegetation communities/habitat types in the Lower Missouri River floodplain. Relationships were determined from old aerial photographs, plat and GLO maps (see Appendix MS-10) geomorphology maps (Appendix MS-2, MS-3), soil maps (Appendix MS-4, MS-5) LiDAR topographic maps (Appendix MS-6), flood frequency maps (Appendix MS-7), ESD relationships (Appendix MS-11), various historical and botanical accounts of the region (e.g., see Lewis and Clark Expedition botanical information in Moulton 1988, Brackenridge 1814, Pound and Clement 1900, Watkins 1921, Aikman 1926, Weaver 1960, Steyermark 1963, Nigh and Schroeder 2002, Steinauer and Rolfsmeier 2003, Nelson 2005, Heitmeyer and Nelson 2014), and land cover maps prepared by the Missouri River Commision in 1879 and 1894 (Appendix MS-8, MS-9).

Habitat type	Geomorphic surface	Soil type	Flood frequency
Mesic Prairie	Remnant Glacial terrace	loam and silt loam	On-site precipitation; > 10 yr.
Wet-mesic Prairie	Remnant Glacial terrace, high elevation point bar	loam and silt loam	On-site precipitation and surface/ground water discharge - 2-5 yr.
Wet bottomland prairie	Alluvial floodplain and floodplain depressions	silt loam and silty clay loam	Seasonal
Bottomland Marsh	Floodplain depressions and abandoned channels and swales	Clay and silty clay	Annual, ranging from semipermanent to multi-year inundation
Riverfront Forest	River edge, bar and chute, islands, abandoned channel	Sandy, gravelly, silt	Annual with variable inundation depending on river stage
Floodplain Forest	Alluvial floodplain ridges and higher elevation flats, natural levee	Silt loam, silt clay	Seasonal, > 2-5 yr.
Slope Forest	Alluvial and colluvial fans	Mixed erosional	> 100 yr.

Osage Reach

Both the ESD and GLO maps (Appendices MS-10, MS-11) suggest the narrow Missouri River floodplain from the mouth of Osage River to near St. Charles was covered with forest, with a few exceptions. Early succession riverfront forest types tended to dominate the reach in the alternating bottom-island morphology of the frequently meandering river channel distribution. Floodplain forest species encountered in GLO surveys were scattered throughout the Osage Reach forests, mainly on the very highest floodplain elevations and on ridges of islands or point bars. The GLO maps suggest some possible prairie or savanna in the Hancock and Labodie Bottoms south of the Augusta-Klondike, Missouri area and in the Greens Bottoms just west of Creve Coeur, Missouri. The Hancock and Labodie Bottoms contained some trees such as elm, hackberry, and box elder at the time of the GLO (Appendix MS-10), while the Greens Bottoms did not. ESD information, based on recent soils reflects lateral river migration in these areas since the GLO and likely reflects a change in community structure over time to a more forested state in these areas at the present time. The GLO prairie at Greens Bottoms appears as a southern lobe from the more extensive historical prairie north to the St. Charles area.

East of St. Charles the LMR floodplain contained forest along the Missouri and Mississippi river corridors with a large contiguous prairie occupying the sediment dome, or terrace, between the rivers. The large Marais Temps Clair oxbow and the smaller older Marais Croche swale represent former river channels with bottomland lake marsh habitats. Another remnant abandoned channel lake, Creve Coeur Lake, is present along the river bluff near Maryland Heights, Missouri. The extensive bottomland prairie in the St. Charles confluence region likely contained wet prairie marshes in some deeper swales and conversely was bounded by oak-savanna where the terrace graded to more recent alluvial river channel belts (see maps and discussion in Heitmeyer and Bartletti 2012). ESD maps also suggest some floodplain marsh areas in the Osage Reach floodplain west of Washington, where remnant clay deposits occur; these areas also may have supported scattered, mostly isolated, wet bottomland marsh embedded in floodplain forests.

Grand Reach

With the exception of the area south of Brunswick between the Grand and Chariton rivers, the type and distribution of historical communities in the LMR floodplain in the Grand Reach resembled those in the Osage Reach west of St. Charles. This Grand Reach river floodplain is narrow and contains alternating loop and long bottoms. The Missouri River frequently moved laterally in this reach, where sediments deposited and scoured to create relatively “young” soils that supported mostly early succession forest communities. GLO maps suggest a few possible prairie or savanna inclusions in the otherwise forested Grand River floodplain including sites just north of the entry of the Osage River, around New Franklin, Missouri and west of Glasgow. Generally, the GLO surveys found more floodplain forest species in the long bottom areas, such as the current Overton Bottoms area, compared to predominantly riverfront forest species along the river channel and in loop bottoms (Appendix MS-10). The Osage and New Franklin areas appear to have been surrounded by forests and some oak, elm, and box elder trees also were noted, suggesting the sites may have been a more open woodland. The site west of Glasgow represents the eastern extension of the large terrace prairie that historically occurred south of the Missouri River in the Marshall Plain around Slater, Missouri (Nigh and Schroeder 2002). ESD maps (Appendix MS-11) suggest some areas of wet bottomland prairie and marsh were present in the Grand Reach south of Glasgow, based on clay and silty clay soils, but the GLO survey record indicates these sites formerly supported forest stands in most places. Nonetheless, some notably larger wet bottomland prairie sites from the ESD maps occurred along the north bluff east of Jefferson City, Missouri and around New Franklin, and also just south of the I-70 Bridge at Overton Bottoms (see also notes about possible prairie at Overton Bottoms in Thogmartin et al. 2009).

Both the ESD and GLO maps indicate a marked transition from forest to prairie in the area between the entry of the Grand and Chariton rivers south of Brunswick. Areas immediately along the Missouri River channel and southwest of Dalton Cutoff Lake were forest, but the ESD maps suggest that wet-mesic prairie occupied higher less frequently flooded sites, while wet bottomland prairie and marsh occurred northwest and east of Dalton Cutoff all the way to the Chariton River corridor. On June 13, 1804, Meriwether Lewis described the area where Grand River entered the Missouri River as “ …just above a beatifull and extensive prarle … Above the entrance of this river the lands are extremely fertile: consisting of a happy mixture of prairies and groves, exhibiting one of the most beatifull and picteresk seens that I ever beheld” (from Moulton 1988). The first soil maps of this area published in 1921 noted that large areas of the floodplains between the Grand and Chariton rivers supported “a luxuriant growth of coarse wild grass” (Watkins et al. 1921). GLO maps agree with ESD prairie description, except that the GLO survey mapped the prairie as terminated just west of the Old Chariton River channel and was forest from there to the east. The GLO survey notes and maps clearly show an abundance of trees along the Chariton River floodplain.

Kansas Reach

The Missouri River floodplain widens east of Richmond where it travels through the less resistant Pennsylvanian limestone and shale bedrock. This wide, relatively flat area east to the entry of the Grand River historically contained a narrow band of forest immediately adjacent to the Missouri River and along the Grand and Crooked rivers, and then contained expansive prairie both north and south of the river. The western extent of the prairie was about Sunshine Lake. GLO survey notes indicate some scattered trees occurred along the northern edges of the floodplain prairies near upland bluffs and rises, which likely was a band of savanna with many oaks present (Appendix MS-10). ESD maps suggest frequently flooded sites with clay and silt clay soils probably contained wet bottomland prairie and marsh including areas adjacent to the terrace prairie south of Miami, in areas along the Wakenda River and Wakenda Slough area, and a large clay-based surface east of Hardin, Missouri (Appendix MS-11). Areas west of Sunshine Lake were apparently mostly forested although both the GLO and ESD maps indicate pockets of remnant prairie communities north and east of Cooley Lake and south of Atherton, Missouri. GLO surveys found both floodplain and riverfront forest species west of Sunshine Lake, but generally more floodplain forest trees were encountered here than in any other LMR area (Appendix MS-10). The GLO surveys also indicate prairie extended into the floodplain east of Buckner, Missouri along Fire Prairie Creek. This prairie was part of a lobe of the large expansive prairie that formerly was southeast of Kansas City. Bottomland lakes and marshes were present in several Kansas Reach sites including the larger Sunshine and

Cooley lakes and smaller Hicklin, Teteseau, and Big lakes and Cranberry Chute.

Nodaway Reach

GLO data and ESD maps indicate the relatively narrow and young LMR between St. Joseph and Kansas City was heavily forested, mostly with early succession tree species, especially cottonwood and sycamore (Appendices MS-10, MS-11). A few scattered oak and pecan occurred mainly along floodplain bluffs. The larger Bean, Lewis and Clark, and Contrary lakes contained bottomland lake communities and several other older channel swales also likely contained either wet bottomland prairie or marsh habitats. The GLO notes indicate prairie ranged into the LMR floodplain in the St. Joseph area, which represented the far west extension, or small lobe, of the extensive prairies east of St. Joseph.

Platte Reach

North of St. Joseph, the LMR historically was characterized by forest in variable widths along the Missouri River channels and then sharp transitions to prairies away from the immediate river corridor. Smaller tributary rivers, streams and creeks bisected the prairies and contained narrow corridors of riverfront tree species along them especially along the larger Tarkio, Nishnabotna, and Wabonsie rivers. GLO maps typically suggest a wider, more extensive, area of prairie in the Platte Reach than the ESD maps in Missouri (Appendices MS-10, MS-11). For example, ESD maps show forest along many east river bluff areas, while the GLO maps prairie to the bluff edge and beyond in most areas. The GLO maps identify the interesting "loess-type" forest in the highly dissected loess hills south and west of Oregon, Missouri, north and south of Rockport, Missouri, and at Waubonsie State Park in Iowa, but these forests usually are terminated at or near the base of floodplain bluffs. While GLO maps are not available for Nebraska, a review of specific GLO notes indicates the area west of the current Missouri River channel at the McKissick Island area was bottomland (undetermined whether wet-mesic or wet bottomland type) prairie that graded to upland mesic prairies in the rolling hills of eastern Nebraska. ESD maps from Missouri indicate several areas in the Platte Reach where wet-mesic prairie transitioned to lower elevation more prolonged flooded wet bottomland prairie and marsh habitats. The largest expanse of this wet bottomland prairie occurred from the east side of Squaw Creek NWR north to the Craig, MO area. Other low elevation marsh and bottomland prairie areas also may have been present south of Langdon, west of Watson, and west of Bigelow, Missouri.

Little Sioux Reach

Historical vegetation communities north of the Platte River resemble those immediately to the south in that bands of forest adjoined the recent Missouri River channels and then sharply transitioned to prairie in the expansive floodplains north of Missouri Valley, Iowa and Blair, Nebraska. The Iowa GLO maps clearly show this dichotomy of community types (Appendix MS-10). Although GLO maps are not available for Nebraska, the specific GLO notes from Nebraska also indicate sharp transition from early succession forest along the river channels to prairie in higher off-channel floodplains. Edges of floodplains, especially in Nebraska, often have marked rises in elevations and infrequent flooding frequency (Appendices MS-6, MS-7), which cause prairie types to change from bottomland or wet-mesic types in lower elevations to mesic upland prairie on the high benches of the floodplain edge. GLO notes suggest some relatively narrow bands of savanna between riparian corridors and floodplain terrace flats, many of which apparently had considerable composition of scattered bur oak present. Bottomland lake and marsh habitats were present in larger cutoff oxbows, such as DeSoto, Nobles, Horseshoe, Hanthorn, and Soldier Round lakes.

GENERAL SYNOPSIS OF HISTORICAL COMMUNITY DISTRIBUTION

The available historical information discussed above suggests that the LMR area covered in this study contained diverse, often complex, interspersions of several major community types. General patterns include:

1. Parallel early succession riverfront forest bands occurred in variable widths along the recent Missouri River channels throughout almost all of the LMR from the Little Sioux River to the Missouri-Mississippi River confluence. Similarly, narrower parallel bands of riverfront forest typically adjoined larger

tributaries where they entered and crossed the LMR floodplain to join the Missouri River.

2. Floodplain forest species patches were interspersed with riverfront forest communities throughout the LMR especially in the long bottoms of the Osage and Grand Reaches, the western Kansas Reach, and north of Omaha. Other areas with floodplain forest were mainly high elevation floodplain ridges such as inside point bar bends.

3. Expansive, mostly contiguous, prairie occurred on floodplains away from the above forest along the Missouri River from the Little Sioux River to St. Joseph. Prairie types ranged from mesic upland types on the highest floodplain benches that adjoined higher upland prairie hills to wet bottomland types in floodplain depressions and swales.

3. The narrow incised and relatively young LMR reach from St. Joseph to the entry of the Kansas River was almost entirely covered with forest, mostly early succession species.

4. Extensive, contiguous prairie occupied the wide floodplain and terrace areas from Richmond to Brunswick, and floodplain prairie typically extended and transitioned to upland prairies in west central Missouri.

5. South of Glasgow to St. Charles, the Missouri River floodplain narrows and was dominated by forest throughout the floodplain except for a few prairie lobes that extended from upland prairies into the floodplain.

6. A large peninsula of bottomland prairie occupied the higher elevation sediment mound area between the Missouri and Mississippi rivers. This prairie peninsula represented an extension of prairies than covered eastern Missouri and parts of the Upper Mississippi River floodplain.

7. Newer and larger abandoned channels throughout the LMR, including oxbows and swales, contained bottomland lake marsh habitats that often were historically bordered at least in part by riverfront forest.

Karen Kyle

Surveying Team

Stephens Ferry

Hannah Cole Fort location

CHANGES TO THE LMR ECOSYSTEM

The history of European exploration, occupation, and alteration to the Missouri River ecosystem is one of the most celebrated, documented, and lamented accounts of any area in North America. Starting with the numerous accounts written from and about the Lewis and Clark Expedition of 1804-06 (e.g., DeVoto 1953, Jackson 1978, Moulton 1988, Ambrose 1996) the amazing adventures of explorers, naturalists, and eventual pioneers to the region has been recounted. Beginning with the subsequent settlement of the Missouri River Valley in the 1800s, continual attempts were made by man over the next 150 years to change and manage the river and its floodplain. The vigilance to trying to develop and manage the river as a major navigation route, and then later to control its discharges to reduce flood damage, is captured in several fascinating accounts (e.g., Ferrell 1993, 1996; Thorson 1994; Schneiders 1999). Perhaps no other large river system in North America has been so dramatically altered, yet seemed constantly resilient, in the ecological and physical structure and forces it embodies. It is beyond the scope of this report to write a comprehensive review of all of the information about the changes to the LMR ecosystem since the presettlement time prior to the early 1800s. Many publications provide this history, and the following is only a short summary of the major changes that have affected the ecology of the LMR so as to provide a foundation for evaluating the potential to restore at least some of its degraded or destroyed attributes that is provided in the next section of this report.

SETTLEMENT AND EARLY LANDSCAPE CHANGES

Human occupation of the LMR apparently first occurred in the Paleo-Indian period 8,000 to 12,000 years BP (Wedell 1943; Chapman 1975, 1980; Hudson 1976). Archaeological evidence from several LMR sites suggests seasonal camps were present in, or on the edges, of the Missouri River floodplain and its larger tributaries with more permanent camps located on higher elevation terraces and adjoining uplands (e.g., Bray 1980). Early people in the LMR apparently were highly nomadic and relied on seasonal subsistence in multiple areas to hunt large mammals, exploit seasonally available fish and other foods in the Missouri River and its floodplain habitats, and to gather native food (Ewers 1968).

During the post-Wisconsin glacial period, the LMR north of the current Missouri River was changing from a boreal forest dominated ecosystem to a deciduous oak-hickory forest (Delcourt and Delcourt 1990, Delcourt et al. 1999) and small bands of native people hunted large nomadic mammals such as bison and mammoth. Climatic conditions began to dry during the Middle Archaic period (about 5,000 to 8,000 BP) and prairies expanded throughout glacial terraces and drift plains and displaced forest except along major drainages. Likely the extent of prairies in the glacial plains into north Missouri, both upland and bottomland types, reached their maximum distribution during the Altithermal period of 4,000 to 8,000 BP (Schroeder 1982). In the prairie dominated landscape, bands of native people likely were highly mobile, followed herds of large ungulates, and occupied lower elevation floodplains primarily during dry periods of summer. By the Late Archaic period 2,500 to 5,000 years BP, wetter climates prevailed and forests expanded along drainages in the LMR. At this time both mobile and sedentary people began more intense harvesting of wild seeds and started some small cultivation of plants to supplement hunting and fishing along the Missouri River.

Climate and vegetation distribution in the LMR during the Woodland period, 1,600 to 2,000 BP apparently were relatively similar to 19th century conditions. During this time native villages probably became more socially oriented and relied on wild food gathering, hunting, fishing, and small cultivation plots (Chapman 1980, Nelson 2005). Large vertebrate remains found in middens of this period reflect changes in hunting technology, and maize horticulture began to occur in village sites along tributaries such as the Grand River and on higher floodplain elevations. The Mississippian period of human occupation in the LMR marks the first evidence of permanent year-round villages and extensive maize agriculture about 900 years BP (Chapman 1980). The sites of maize culture likely were on silt loam prairie terrace locations that did not flood regularly. Indians from throughout the LMR and adjacent areas traded along the Missouri and Mississippi rivers and frequent conflicts among plains bands of people occurred (e.g., Dolin 2010).

In the last 500 years, villages of native people declined throughout the Missouri River drainage as regional conflicts, warfare, and introduction of European diseases decimated native populations. Early explorers of the Missouri River Basin, including Lewis and Clark encountered native people throughout their travels and described the LMR as a vast complex of prairie, floodplain forest, and interspersed bottomland lakes and marshes (e.g., see Moulton 1983, Eckberg and Foley 1989). GLO surveys in the early 1800s indicated few permanent European settlements or agricultural fields at that time.

French control of the LMR region influenced the region with scattered camps of trappers, miners, and explorers from the late 1700s through the early 1800s (Larpenteur 1933, Wells 1948, Dolin 2010). The earliest and furthest west outpost on the Missouri River, Fort Orleans, established French presence in the area and began to displace native Osage and Missouri Indian tribes. The city of St. Louis was founded in 1764 and all early European settlements west of the city were on or near the Missouri River. The first European settlers came to the LMR region shortly after the Lewis and Clark expeditions, but extensive settlement did not occur until after 1830 (Boehner 1937). St. Louis quickly developed into the primary trading post in the Missouri and Mississippi River valleys following the advent of steamboats in the early 1800s and rapid expansion of European populations and settlements into these regions occurred during the 1840 to 1860 period; by 1860 the population of St. Louis had increased to 160,000 making it the largest central U.S. City (Brauer et al. 2005). Kansas City was formally established in 1853, and it also enlarged quickly to a population of about 50,000 by the late 1800s. Agricultural activity in the mid to late 1800s in the LMR was restricted to some clearing of trees on natural levees along the Missouri River and its tributaries for steamboat fuel, firewood, dimensional lumber and for small crop fields (e.g., Chittenden 1903). Most wet bottomland prairie areas were not farmed because early farm equipment could not plow or break the dense clay and silt clay soils. Early settlers also believed that land without trees was less fertile and could not grow good row crops (Boehner 1937). Despite early attempts to harness parts of the Missouri River, grazing and timber clearing probably had the greatest impact on the river and its tributary channels until the late 1800s. While steam-powered snag boats began removal of some snags from the Missouri River immediately upstream of St. Louis in 1838, and a large tonnage of snags were removed, the snagging effort was largely random for the first 50+ miles of the river and generally of little impact through the late 1800s (Suter 1877, Chittenden 1903, Schneiders 1999). In contrast to limited changes to the river channel proper, land cover maps prepared for the LMR in the late 1800s identify the substantial conversion of floodplains to agricultural uses by the late 1890s (Appendices MS-8, MS-9).

After the Civil War, increased settlement of the LMR occurred when railroads were built throughout the area in the 1870s and 1880s (e.g., Boehner 1937, Wells 1948). New immigrants laid out farms on ridges and broader prairie uplands, and wire fencing established contained grazing areas. Increasing livestock production in the prairie part of the LMR also led to extensive haying and grazing of prairies, including floodplain sites. Improved farm implements facilitated both plowing and hay-cutting on prairies and gradually considerable prairie areas were converted to agricultural production by the late 1880s (see Appendix MS-9). Settlement and the need for transport of agricultural and other commodities ultimately led to the construction of an extensive network of roads and rail lines throughout the LMR.

LATER LANDSCAPE AND HYDROLOGICAL/ECOSYSTEM CHANGES

A comprehensive chronology of events that eventually destroyed and degraded the Missouri River channel and its floodplain is provided in several accounts (e.g., Thorson 1994, Schneiders 1999) with an especially concise table provided in Galat (1996, Table 3). Major civil works undertaken by the USACE on the river included efforts to channelize, deepen and straighten the river; maintain a navigation channel of at least six feet, impound the river in upstream areas, and operate impoundment reservoirs to regulate downstream flows and reduce flood potential and damage. The ultimate ecological effects of these works are summarized in Table 4.

Efforts to channelize the Missouri River started in earnest after 1885 when large woody debris (snags) were first removed from the river. Subsequent dredging and construction of dikes, revetments, and levees sought to create a more stable navigation channel, which ultimately greatly shortened the river channel length, cut off meanders, and significantly affected off-channel floodplain habitats (Funk and Robinson 1974). Currently, the Missouri River from Sioux City, IA to St. Louis is channelized in some form and high levees generally confine the river to a width range of about 550 to 1000 feet (Schmulbach et al. 1992). Between 1879 and 1972 the surface water area in the Missouri River between Rulo, Nebraska and St. Louis declined by 50% and islands were essentially eliminated and chutes and sloughs that separated island from the shore also were eliminated (Funk and Robinson 1974, Halberg et al. 1979). One of the most damaging consequences of the channelization and levees is the current extensive isolation of the river from its floodplain except during extreme flood events. Maps of current large main stem levees and areas within levee, drainage, and flood protection districts demonstrate the magnitude of this effect (Appendix MS-12). Channelization also has many other negative ecological consequences including changes in flow velocity and distribution, temperature, oxygen, and sediment transport (e.g., Brookes 1988, Galat et al. 1996).

After years of mainly failed attempts to fully channelize and improve the Missouri River for navigation purposes, civil works on the river began to embrace and pursue flood control as a primary objective of USACE projects and authority in the river valley starting in the 1940s (Schneiders 1999). Widespread flooding during the early 1940s was the impetus for the 1944 Flood Control Act, which authorized a six-dam system of impoundments on the upper river to control downstream discharge and flooding (Keenlyne 1988). This act embodied the "Pick-Sloan Plan …" to provide for the most efficient utilization of waters of the Missouri River Basin for all purposes including irrigation, navigation, power, domestic and sanitary purposes, wildlife, and recreation (U.S. House of Representatives Report 475, 78th Congress, Second Session, 1944). The first dam and reservoir constructed was Fort Peck in 1940 and the final dam and reservoir was Big Bend completed in 1963. The collective storage capacity of 91.5 cubic kilometers in the six reservoirs is the largest such capacity in the U.S. (Ferrell 1993, 1996). The flood control capacity of these large impoundments was eventually supplemented with construction of more than 1,300 smaller impoundments and farm ponds throughout the Missouri River Basin (Schmulbach et al. 1992).

Currently about 35% of the Missouri River length is impounded (Norton et al. 2014). The largest tributaries of the river by drainage area are the Yellowstone, Cheyenne, Platte and Kansas rivers, of which only the Platte and Kansas enter downstream of Gavins Point Dam. The effects of impoundments and regulation of Missouri River flows are well documented (see e.g., Galat et al. 1996, Hesse 1996, Galat and Lipkin 2000, Jacobson and Galat 2006). As a direct impact of these main stem alterations, sediment loading in the river has declined by 67 to 99 percent at various locations in the LMR, and current mean turbidity at the mouth of the Missouri River at St. Louis has decreased four times from turbidity values of the 1930s. Changes in sediment loading have significantly altered suspended sediment particle size, periphyton growth, and river fisheries. Sediment retention of dams, coupled with the erosive nature of water releases below the dams, has led to deg-

Table 3. Selected chronology of significant events in the history of the LMR development. (From Galat et al. 1996).

Year	Event
1803	Acquisition of basin to United States from France through Louisiana Purchase.
1804–1806	Captains M. Lewis and W. Clark expedition of Missouri River from mouth at St. Louis, Missouri, to origin in Montana.
1819	First steamboat travel on Missouri River.
1829	First commercial steamboat barge line: St. Louis to Leavenworth, Kansas; steamboat era begins.
1832	Snag removal authorized under act of Congress.
1838	2,245 large trees removed from river channel and 1,700 overhanging trees cut from bank in 619 kilometers of river upstream from St. Louis.
1867–1868	Major C. W. Howell's Survey and Report on Improvement of Missouri River.
1869	Peak of steamboat era; 47 steamboats deliver about 9,000 metric tons of cargo to Ft. Benton, Montana, 3,540 kilometers upstream from St. Louis.
1881	Lt. Col. C.R. Suter's report detailing long-range plans for aiding navigation on river.
1884	Missouri River Commission established by Congress to improve navigation of river by contracting its width, stabilizing channel location, protecting banks from erosion, and snag removal.
1885–1910	Snag removal systematic and intensive; 17,676 snags, 69 drift piles, and 6,073 overhanging bankline trees removed in 866 kilometers of river in 1901 alone.
1902	Repeal of act establishing Missouri River Commission. Railroads dominate freight traffic; steamboat era ends.
1902	Congress enacts Reclamation Act of 1902 (Public Law (PL) 57–161) to survey, construct, and maintain irrigation works in arid lands of the western United States. Start of reservoir development planning.
1902–1912	No maintenance of Commission structures, most wash out.
1910	Increase in typhoid deaths in towns along Missouri River.
1912	Congress authorizes 1.8-meter-deep, 61-meter-wide channel from Kansas City, Kansas, to St. Louis, Missouri (PL 62–241).
1912–1917	Active dike and revetment construction to stabilize channel.
1913	U.S. Public Health Service (USPHS) report identifies sewage pollution in river as a major factor in typhoid deaths.
1917–1933	Maintenance of channel structures, active period of levee construction.
1920–1958	Records and studies of water suppliers and USPHS confirm bacterial contamination. Treatment by most water suppliers does not meet USPHS standards.
1925	PL 68–585 authorizes 200-foot-wide channel, Kansas City, Missouri, to mouth.
1927	Extension of 1.8-meter-deep channel to Sioux City, Iowa (PL 70–560).
1934	Passage of Fish and Wildlife Coordination Act (PL 73–121) requiring that fishes and wildlife receive equal consideration to other purposes of Federal planning in federally funded or approved water-development projects.
1936	Passage of Flood Control Act (PL 74–738) to develop "works of improvement" on more than 50 major rivers throughout the United States.
1937	Construction completed on the first main-stem dam and impoundment on Missouri River, Fort Peck Dam and Reservoir, Montana, to supply water for river navigation.
1944	Flood Control Act of 1944 (PL 78–534) authorized Pick-Sloan Plan to construct six dams on main stem of Missouri River. Missouri River Bank Stabilization and Navigation Project authorized for flood control, bank stabilization, land reclamation, hydropower generation, and development and maintenance of navigation channel.
1945	Rivers and Harbors Act (PL 79–14) passed, provided a 2.7-meter-deep, 91.4-meter-wide navigation channel from St. Louis to Sioux City.
1946	Fish and Wildlife Coordination Act of 1946 (PL 79–732) passed, required Federal agencies to construct water projects with a view to preventing loss of and damage to wildlife resources.
1946–1955	Five additional dams and reservoirs constructed on Missouri River. See table 5–4 for details.
1956	Federal Clean Water Act (PL 84–660) passage strengthens water-quality regulations.
1958	Fish and Wildlife Coordination Act of 1958 (PL 85–624) required that project costs must include the cost of water project modifications or land acquisition earlier required under PL 79–732 to prevent loss or damage to wildlife.
1960–1981	Replacement of permeable pile dikes with impermeable rock dikes.
1960–1970	Construction of primary wastewater-treatment facilities for major discharges on lower river.
1964	Fish kill in Missouri River extending more than 161 kilometers downstream from Kansas City, Missouri.
1965	Federal Water Project Restoration Act (PL 89–72) required non-Federal public agencies to administer fish, wildlife, and recreation on project lands and pay one-half of costs allocated to these resources.
1969	Flavor tests reveal unacceptable taste in fishes from several locations in Missouri River. PCB levels in common carp pose potential threat.
1969	Federal Water Pollution Control Authority, and later, U.S. Environmental Protection Agency (USEPA), establishes requirements of downstream minimum daily average flow to maintain federally approved water-quality standards.
1970–1971	25 percent of fishes sampled from a bay in Lake Oahe, South Dakota, contained unsafe levels of methylmercury. Source of mercury was mining operations on a tributary stream.

Continued next page

Table 3, continued. Selected chronology of significant events in the history of the LMR development. (From Galat et al. 1996).

Year	Event
1970–1974	PCBs, aldrin, and dieldrin levels in fishes at Hermann, Missouri, pose potential health threat.
1971	USEPA study reveals levels of *Salmonella*, fecal coliform bacteria, and viruses in Missouri River present a potential hazard for drinking water or recreation.
1972	Federal Water Pollution Control Act of 1972 (PL 92–500) passed, requiring USEPA to establish national effluent and toxic discharge standards.
1972–1988	Construction of secondary wastewater-treatment facilities for most major dischargers to lower river.
1973	Endangered Species Act (PL 93–205) passed, requiring U.S. Fish and Wildlife Service (USFWS) to list species threatened or endangered with extinction; authorizes programs for their recovery; prohibits authorization of Federal projects that jeopardize listed species or their habitats. See table 5–6 for federally listed Missouri River biota.
1975–1980	U.S. Army Corps of Engineers (USACE) constructs environmental notches in 1,306 wing dikes from Sioux City to St. Louis to create fish habitat on downstream side of dike.
1976–1978	PCBs, aldrin, dieldrin, and chlordane residues in fishes exceed safe limits.
1976	Toxic Substances Control Act (PL 94–469) passed, phasing out use of PCBs and restricting use of chlordane.
1977	Clean Water Act of 1977 (PL 95–217) established national effluent standards for water pollutants; required cities to implement secondary sewage treatment and provided Federal grants to aid construction; set target date for discharge elimination of 129 priority pollutants; required USEPA permit for point source discharge of pollutants.
1978	240 kilometers of free-flowing Missouri River in Montana and 93 kilometers below Gavins Point Dam incorporated into National Wild and Scenic Rivers System.
1980	37 common industrial solvents (13 metals, 23 organic compounds, and cyanide) detected in St. Louis water-treatment plants.
1984–1986	Chlordane levels in fish flesh from lower Missouri River reported to exceed safe limits for consumption.
1986	Water Resources Development Act (PL 99–662) authorizes USACE to mitigate aquatic and terrestrial habitat losses from past projects.
1987–	Missouri Department of Health advisories issued warning against consumption of specific commercial fish species from areas of Missouri River due to toxic contamination.
1988	Missouri River Natural Resources Committee established to promote preservation, wise utilization, and enhancement of natural and recreational resources of Missouri River.
1988–1990	Major drought in Missouri River basin. Water shortage precipitates conflict over water allocations for navigation versus recreation. USACE initiates master manual review and updates to develop and evaluate alternative water-management operations for main-stem reservoir system.
1989	Mississippi Interstate Cooperative Resource Agreement (MICRA) formed by various entities in the Mississippi River basin (see text).
1989–	More stringent permit limitations on discharge of toxic metals and organics imposed on wastewater-treatment facilities of major cities along lower Missouri River, Missouri.
1990–	Upper Missouri River basin States (Montana, North and South Dakota) sue USACE, claiming reservoir operation should consider upstream recreation needs in addition to lower river navigation needs for water releases.
1990	Missouri River Initiative (Missouri River—Conserving a River Ecosystem, MOR-CARE) formed to facilitate cooperation among governmental, tribal, and private parties for optimal recovery of natural resource values and environmental health of Missouri River ecosystem (see text).
1990	Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (PL 101–646) passed to prevent and control infestations of coastal inland waters by zebra mussel and other nonindigenous aquatic nuisance species.
1991	USACE mitigation projects begin on lower Missouri River, include land purchases in floodplain and construction to enhance aquatic resources (see text).
1991	A 63-kilometer section from Fort Randall Dam to headwaters of Lewis and Clark Lake, including 40 kilometers of lower Niobrara River and 13 kilometers of Verdegie Creek, designated a national recreation river.
1991	Missouri Department of Conservation publishes big river fisheries 10-year strategic plan.
1992	Introduction of Gunderson Bill (House bill 4169) to establish a Council on Interjurisdictional Rivers Fisheries and to provide funds to MICRA to conduct a comprehensive study of the status, management, research, and restoration needs of fisheries of Mississippi River drainage basin (see text).
1992	Closure of commercial fishing for all catfish species in lower Missouri River (see text).
1993	The "great Midwest flood of 1993," a hydrometeorological event without precedent in modern times. Peak discharge rate exceeded the 100-year flood value at 45 U.S. Geological Survey streamflow gaging stations in the Upper Mississippi River Basin (upper Mississippi in Illinois, lower Missouri, and their tributaries). Estimates of total damage range between $12 and $16 billion.

Table 4. Summary of effects of river channelization (C); including snag removal and construction of dikes, revetments, and levees; construction and operation of main stem dams (D); and both types of alterations (CD) on the LMR ecosystem (from Galat et al. 1996).

Cause	Effect
	Physical
C	Changes in channel geomorphology: 8 percent reduction in channel length 27 percent reduction in bank-to-bank channel area 50 percent reduction in original surface area of river 98 percent reduction in surface area of islands 89 percent reduction in number of islands 97 percent reduction in area of sandbars resulting in reduction in channel diversity through loss of side channels, backwaters, islands, and meandering (Funk and Robinson, 1974; Hesse and others, 1988).
C	Change in physical substrate from dominance of silt, sand, and wood to rock riprap.
C	Increased water depth and velocity in main channel.
D	Preimpoundment versus postimpoundment declines in suspended sediment loads at Omaha, Nebraska, and St. Louis, Missouri, from 175 to 25 and from 250 to 125 million tonnes per year (Schmulbach and others, 1992).
D	Reduction in river sediment load, resulting in channel bed degradation, including channel deepening, increased bank erosion, and drainage of remnant backwaters downstream from dams (Hesse and others, 1988, 1989a, 1989b).
D	Silt-clay fraction of suspended sediment load reduced by 50 percent, but sand fraction increased 260 percent, following closure of Gavins Point Dam in 1954 (Slizeski and others, 1982).
D	Reduction in turbidity, resulting in increased light penetration (Morris and others, 1968; Pflieger and Grace, 1987).
D	Modification of natural flow regime by evening out the maximum and minimum discharges and eliminating periodic flood pulse.
D	Reduction in annual temperature range.
CD	Loss of periodic flooding and floodplain connectivity.
	Chemical
C	Higher water velocities reduce travel time for dissolved ions, nutrients, and contaminants.
D	Increase in dissolved oxygen concentrations below main-stem dams (Morris and others, 1968).
D	Higher postimpoundment summer flows for navigation dilute impacts of point source discharged pollutants (Ford, 1982).
D	Reductions in nitrogen and phosphorus concentrations downstream from reservoirs and changes in spiraling patterns (Ward and Stanford, 1983; Schmulbach and others, 1992).
	Biological
C	Decline in habitat richness results in presumed decrease in diversity of periphytic algae (Farrell and Tesar, 1982).
C	Elimination of plankton and invertebrates produced in standing water chutes and sloughs due to loss of these habitats (Whitley and Campbell, 1974).
C	Loss of instream snag habitat and functions of organic matter retention and substrate for invertebrates and fishes (Benke and others, 1985).
	Biological—Continued
C	Greater standing crop of benthic invertebrates in mainstream of unchannelized versus channelized river sections (Berner, 1951; Morris and others, 1968; Nord and Schmulbach, 1973).
C	Smaller standing crops of benthic invertebrates in chutes and mud banks of unchannelized versus channelized sections (Morris and others, 1968).
C	Standing crop of drift larger in unchannelized than in channelized sections of river, and little similarity between drift and benthos (Morris and others, 1968; Modde and Schmulbach, 1973).
C	67 percent reduction in benthic area suitable for invertebrate colonization (Morris and others, 1968).
C	54 percent decline in benthic invertebrate production from all unchannelized habitats of Missouri River downstream from main-stem dams between 1963 and 1980, and 74 percent decrease in production in chute/backwater habitats (Mestl and Hesse, 1992).
C	Loss of river-floodplain connection for fish migration, spawning, and rearing.
C	Reduction in microhabitats, resulting in decreased abundance of fish species in channelized versus unchannelized section of river in Nebraska (Schmulbach and others, 1975).
C	Higher standing crop of sportfishes in unchannelized sections of river in Nebraska compared with channelized sections, attributed to more backwater habitat and greater habitat diversity (Groen and Schmulbach, 1978).
C	Loss of nesting habitat for sandbar/sand island birds (e.g., *Sterna albifrons, Charadrius melodus*) leading to drastic population declines.
D	Elimination of riparian forests and stream channels in areas flooded by reservoirs, totaling more than one-third entire length of Missouri River (Hesse and others, 1988).
D	Entrainment of fluvial particulate organic matter in reservoirs.
D	Temperature-induced shifts in periphyton and phytoplankton community structure, particularly below dams (Farrell and Tesar, 1982; Reetz, 1982).
D	Increase in periphyton primary production below dams (Ward and Stanford, 1983).
D	Increased relative importance of phytoplankton biomass and primary production compared with upstream allochthonous inputs.
D	Increase in diversity and density of zooplankton community in river downstream from reservoirs (Repsys and Rogers, 1982).
D	Changes in standing crop and diversity, and shifts in functional feeding groups of benthic macroinvertebrates in river downstream from reservoirs (Ward and Stanford, 1979).
D	Alteration of emergence cues, egg hatching, diapause breaking, and maturation of aquatic insects due to thermal modifications below reservoirs (Ward and Stanford, 1979; Petts, 1984).
D	Blockage of riverine fish migration.

Continued next page

Table 4, continued. Summary of effects of river channelization (C); including snag removal and construction of dikes, revetments, and levees; construction and operation of main stem dams (D); and both types of alterations (CD) on the LMR ecosystem (from Galat et al. 1996).

Cause	Effect
	Biological—Continued
D	Inundation of floodplain fish spawning and nursery habitats.
D	Development of extensive sportfisheries in reservoirs and tailwaters (Hesse and others, 1989a).
CD	Near elimination of natural riparian community (Hesse and others, 1988, 1989a, 1989b). Changes reported: –41 percent deciduous vegetation; –12 percent grasslands; –39 percent wetlands
CD	25 percent decrease in postdam tree growth in North Dakota floodplain compared with predam period related to absence of annual soil profile saturation, lowering of water table in spring to reduce downstream flooding (Reiley and Johnson, 1982), and lack of nutrient silt deposition (Burgess and others, 1973).
CD	Increasing proportion of mature forest to other successional stages in remaining floodplain (Bragg and Tatschl, 1977).
CD	80 percent decline in organic carbon load of postcontrol Missouri River to Mississippi River compared with precontrol (Hesse and others, 1988).
CD	Loss of major floodplain habitat types caused reduced populations of associated flora and fauna (Clapp, 1977).
CD	Decreases in endemic large river fishes (e.g., *Scaphirhynchus albus, Polyodon spathula, Cycleptus elongatus, Hybopsis gracilis*) and increases in pelagic planktivores (e.g., *Dorosoma cepedianum, Alosa chrysochloris*) and sight-feeding carnivores (e.g., *Morone chrysops, Lepomis macrochirus*) (Pflieger and Grace, 1987; Hesse and others, 1992).
CD	Population declines of 11 native Missouri River basin biota, leading to listing as federally threatened or endangered (table 5–7).
CD	As much as an 80 percent decline in commercial fishery in Nebraska and 97 percent decline in tailwater recreational fishery below Gavins Point Dam (Hesse and Mestl, 1993).
CD	Decline in legal-sized catfishes in Missouri River, Missouri, attributed in part to increased susceptibility to exploitation due to lost habitat diversity (Funk and Robinson, 1974; Robinson, 1992).
CD	Introduction and establishment of nonnative fishes and invertebrates (e.g., *Oncorhynchus* spp., *Osmerus mordax, Mysis relicta*). See table 5–6 for list of introduced fishes.
	Social
D	Hydroelectric power generation of more than 2.2 gigawatts, sales totaling $1.5 billion from 1943 to 1986 (Sveum, 1988).
D	Development of major reservoir-based recreation and associated commercial services, supported spending of $65 million in 1988 (General Accounting Office, 1992).
CD	Commercial navigation industry transports about 2 million tonnes of goods, producing gross revenues of $17 million in 1988 (General Accounting Office, 1992).
CD	Water supply provided to 40 cities (3.2 million people), 21 power plants, and 2 chemical manufacturers in lower Missouri River (General Accounting Office, 1992).
CD	4,000 percent increase in area of agricultural land use (Hesse and others, 1988).
CD	95 percent of protected floodplain now in agricultural, urban, and industrial uses (Hesse and others, 1989b).

radation in the Missouri River bed as far south as Kansas City (NRC 2002, USACE 2009). LMR reaches immediately downstream of Gavins Point Dam to the confluence with the Platte River south of Omaha are particularly degraded. As channel incision deepens, the possibility of reconnecting the river with the floodplain becomes more remote, and may eventually supersede the effects of many other hydrologic alterations along the river. These changes, may however, be mediated or offset by climate-driven changes in discharge (Gangopadhyay et al. 2012).

Clearly, the other major intended impact of Missouri River impoundments has been the significant alteration to the natural hydrograph of the river itself and flood inundation timing, depth, and duration onto the floodplain (see reviews in Hesse et al. 1988, Hesse and Mestl 1993, Hesse 1996). Once dynamic fluctuations in flow are now dampened, and historically low flows through fall and winter are now elevated for navigation purposes and/or as a result of seasonal water supply releases (e.g., Galat and Limpkin 2000). Specifically, the strong seasonal hydrograph of discharge for the LMR has been flattened (see hydrology graphs in Appendix B) for the April to November period, especially for the upper reaches of the LMR, and reservoir water management has reduced downstream flows that exceed bankfull discharge and subsequent inundation of floodplain habitats (Stalnaker et al. 1989). Prior to 1954, flushing flows at Omaha below the site of the current Gavins Point Dam occurred about every 1.5 years, but since significant flow regulation began in 1954, a large dominant flushing discharge has occurred only three times (see peak discharge data for the Omaha gage in Appendix B2). Closer to the mouth, unregulated tributaries and increased precipitation have coupled to sustain a modest frequency of flushing flows along the lowest reaches of the river (see peak discharge data for the Hermann gage in Appendix B2), however levee systems typically prevent these flows from reaching the surrounding floodplain. A by-product of channel restrictions in the LMR, and a potential opportunity for simulating pre-regulation flood levels, is increased river stage levels since the 1930s for flood-level flows (Criss, no date). For example, gage readings at Omaha, Nebraska City, Rulo, St. Joseph, Waverly, Boonville, and Hermann have all risen significantly by four to nine feet at constant flood-level discharges, and stage increases have been more dramatic at higher flows as a result of levees that now constrict the channel and elevate stages. Conversely, low flows diminished between 1954 and the mid-1990s compared to pre-impoundment periods because of sediment deficits and wing dike effects (USACE 1996, Jacobson and Galat 2006). These lower reaches also are influenced to some degree by inputs from major regulated tributaries (SCS 1982, USACE 1989, 2004a), for example, hydropower releases from Bagnell Dam on the Osage River affect Missouri River dynamics over 100 miles downstream at Hermann (Schubert 2001).

In addition to changes in the physical and hydrological discharge features of the Missouri River, water quality has also changed over time in the LMR and the entire system. Generally, water pollution has occurred in the LMR from contamination of municipal, industrial, and agricultural sources. Urban human sewage along with discharges from meat packing and stockyards has contributed to substantial degradation of water supplies (Ford 1982). Industrial pollution in the LMR comes from petroleum wastes, heavy metals, and PCBs. Agricultural chemical pollution to the Missouri River system includes pesticides, herbicides, and fertilizers (Ford 1982, Schmulbach et al. 1992).

The type and distribution of plant and animal communities and land uses in the LMR, and entire Missouri River, ecosystem has changed dramatically over time. Hesse et al (1988) estimated that during the period from 1892 to 1982, the LMR from Ponca, Nebraska to the St. Louis experienced a 43 times increase in cultivated land at the expense of a 41% decline in woodland and forest, a 39% decline in wetlands, and a 12% decline in grassland. Land surveys along the Missouri River in Missouri from 1826 to 1972 indicated a decline in floodplain forest from 76% to 13% of total land area, while cultivated area increased from 18% to 83% over that time; about 80% of the floodplain was in cultivation by 1958 (Bragg and Tatschl 1977). Other estimates suggest similar dramatic changes in the percentage of floodplain communities in the LMR from 1880 to the present (e.g., Fig. 14). In addition to general native vegetation community loss, certain information suggests marked shifts in specific species composition and seral/succession changes. For example, regenerating forests now have shifted to more early succession stage tree species such as willow and maple corresponding to a decrease in cottonwood due to changes in sediment scouring and deposition and flood frequency (Mazourek et al. 1999, Dixon et al. 2010, Struckhoff et al. 2011, Struckhoff 2015). Several other floodplain plant species now have reduced abundance and/or distribution because of altered flooding regimes including northern pecan, rock elm, blue cohas, purple giant hyssops, wood mint, fragrant white waterlily, and white waterlily (Hesse 1996).

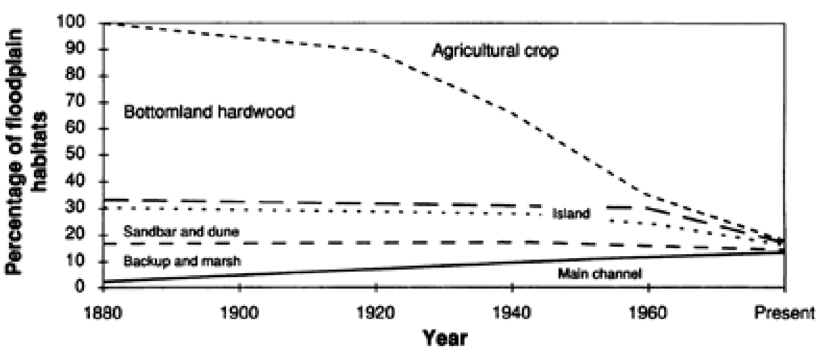


Figure 14. Estimated changes in the percentage of various floodplain habitats between Sioux City, Iowa and St. Louis, Missouri from 1880 to the 1980s (from Hesse 1996).

In addition to plant changes, marked changes in fish and wildlife species throughout the Missouri River Valley, including the LMR, are extensively documented with comprehensive reviews provided in Galat et al. (1996, 2005), Hesse (1996), Smith (1996), and Pegg 2000. In just one striking example, the commercial harvest of fish in the Missouri River declined by 80% from 1947 to 1963 (Funk and Robinson 1974). Lake sturgeon are virtually eliminated from the river and great reductions in paddlefish, flat and blue catfish, and many centrarcids also have occurred.

CLIMATE CHANGE

Within the LMR, temperatures have increased significantly across the entire area since the 1950s (Menne et al. 2012). The upper reaches (upstream of Nodaway River) have shown increases in winter and spring temperature, while lower reaches (those downstream of the Platte River) have increased primarily in the spring and summer. Increases in precipitation trends also have been identified in select regions. Increases in the magnitude and frequencies of rainfall events have been apparent upstream of the Platte River, especially in spring, fall, and summer. No statistically significant increases in total water year precipitation are apparent downstream of the first reach, however.

Because of the high discharge and inter-annual climate variability, the LMR has experienced worsening drought and flood conditions and increased rainfall and discharge rates through the 20th century (Qiao et al. 2013). In response to past climate change trends, the hydrology within the LMR Basin appears to have responded differently in localized areas. Climate changes seem to have had the greatest impact in upper reaches of the study area, while hydroclimatic changes downstream of the Kansas River confluence are not as apparent.

Future hydrologic responses to any continued climate changes in the LMR may vary between reaches. While gradual increases in summer precipitation may be expected in the future, models predict that summer streamflows within the LMR will not likely exhibit strong responses, while water fluxes in all other seasons can be expected to increase with seasonal precipitation variability in fall, winter, and spring (Qiao et al. 2013). River discharge increases of roughly 10% could occur from November to February if climate projections of more intense storms hold true, and the region would likely experience floods of higher magnitudes based on mid-century forecasts.

In addition to the direct impacts of climate change on the hydrology of the Missouri River, the regulation of the main stem dam network, the extent and size of the levee systems and management of tributary reservoirs, will all change in response to flood and drought conditions, thereby producing indirect climate-induced alterations to the river and its floodplain. For example, the water use demands within the western Missouri River Basin, such as the Kansas River Watershed, have prompted the development of water supply reservoirs, whereas flood control reservoirs are more common in the eastern Missouri River Basin (USACE 2004a).

Mehta et al. (2011) found that continental climate conditions can remain stable and influence conditions in the Missouri River basin for years at a time. This decadal climate variability can result in wet or dry periods that persist for years or decades. Alternating climate-induced wet and dry periods along the Missouri River appear to occur in a cyclical pattern. The frequency of this cycle changes from upstream to downstream. For example, the 5-year moving average of mean annual streamflow from the Missouri River at Sioux City (Fig. 15) indicates a post-regulation cycle which hovers largely around the mean with prolonged low flow periods alternating with high flow periods on a 5-15 year basis. The relative consistency in mean annual streamflow, along with its position in the upper reaches of the LMR; suggest that the cycle strongly reflects regulatory releases. Although still visible, the cyclical climate signal is largely muted due to the influence of the dams. In the lower reaches of the LMR mean annual streamflow data indicate more variability and clearer post regulation trends in wet versus dry cycles. The 5-year moving average of gage data from the Missouri River at Hermann shows high flow conditions occur approximately every 10 years and last in duration for five years on average (see Appendix B7c-f). The higher variability and more distinct cyclical pattern of high and low flow periods in the lower reaches of the River reflect the contribution of non-regulated tributaries and their influence on restoring some of the historic variance to the river and its floodplain.

Recent analyses indicate significant trends in annual and seasonal flows of major tributaries, and in the Missouri River itself (Norton et al. 2014).

In general, the headwaters of the Missouri River basin along with the Kansas River watershed had decreasing streamflow over the period of 1960-2011, while tributaries originating from South Dakota, most of Nebraska, and western Iowa all showed trends of increasing streamflow over the same period, particularly in autumn and summer (Norton et al. 2014). Since many of these gages were part of the Hydro-Climatic Data Network (HCDN, Appendices Introduction), it is likely that climate forcing has partially contributed to increases in hydrologic flows for inputs associated with the upper reaches in the study area. The negative trends identified in the Kansas River drainage basin, mostly identified in the summer months, may be more directly related to stream regulation and water use than climate patterns.

a

b

c

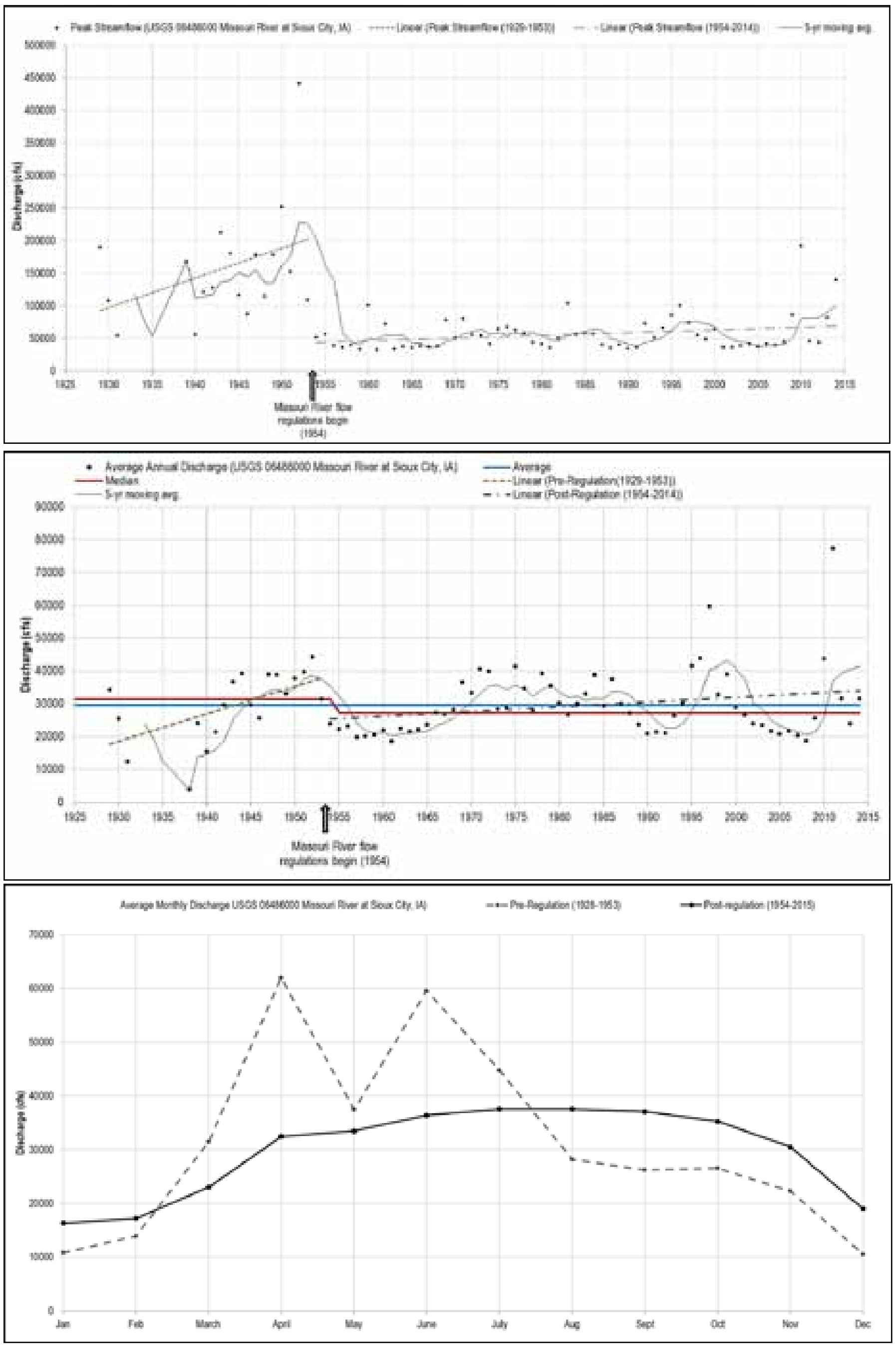


Figure 15. Missouri River: a) annual peak streamflow; b) average annual discharges; and c) average monthly discharges for pre- (1928-1953) and post- (1954-2015) regulation periods at Sioux City, Iowa (USGS gage 06486000).

POTENTIAL FLOODPLAIN ECOSYSTEM RESTORATION OPTIONS

After decades of degradation to the Missouri River and its floodplain, interest in protecting and restoring parts of the ecological integrity of the LMR began to increase in the late 1970s and early 1980s (see e.g., USACE 1981, USFWS 1999, NRC 2002). A major event occurred when the 1986 Water Resources Development Act authorized the USACE Missouri River Bank Stabilization and Navigation Fish and Wildlife Mitigation Project. This "Mitigation Project" was designed to compensate for fish and wildlife habitat losses that resulted from past channelization efforts south of Sioux City and is authorized to purchase and restore up to 166,750 acres to benefit fish and wildlife habitats (USACE 2003, 20011). This project to date has acquired about 17,000 acres from Kansas City to St. Louis and transferred management of land to MDC and the USFWS (USFWS 2014:7). In 2000, the USFWS released a Missouri River Biological Opinion, which was further amended in 2003, to protect and recover endangered species that use Missouri River habitats through flow management, habitat restoration, rearing and stocking, and continued study in an adaptive management framework (USFWS 2000, 2003). Using recommendations from the Biological Opinion, the USACE initiated the multi-partner Missouri River Recovery Program (MRRP) to achieve Missouri River ecosystem recovery goals (USACE 2003, 2011). MRRP efforts have included projects to "direct" succession and diversity of floodplain habitats. Specific elements of the MRRP include restoration of "Shallow Water Habitat" (SHW) created by channel widening and restoration of river chutes and side channels. The program also enhances objectives set to recover several endangered species such as least tern, piping plover, and pallid sturgeon, among others (e.g., Dinan et al. 1985, Dryer and Sandvol 1993).

In addition to the MRRP several other ecosystem conservation initiatives have sought to restore habitats in the LMR. These include the USFWS Missouri River Initiative; establishment of the Big Muddy National Fish and Wildlife Refuge; state strategic conservation plans; USDA WRP easements; and other state, regional and local conservation programs (e.g., Brabander 1992; Hesse et al. 1989; USFWS 1999, 2005, 2013, 2014; Galat et al. 1996). Several documents have advanced suggested approaches for restoration of the Missouri River ecosystem, especially in-channel works (e.g., Hesse and Mestl 1993, Hesse et al. 1989a,b; 1992; Galat et al. 1996, 1998; Jacobson and Galat 2006; Jacobson et al. 2009, 2011, 2015). Additionally, LCPI models that help inform restoration of LMR floodplains recently have been completed from Gavins Point to St. Louis (Jacobson et al. 2007, Chojnacki et al. 2012, Struckhoff 2015). Collectively, the above restoration documents have identified the following objectives:

1. Reestablish a semblance of the pre-control natural hydrograph of the river below Gavins Point Dam.
2. Reestablish natural overbank flooding and river-floodplain connectivity where possible.
3. Reestablish a semblance of the pre-control sediment regime below main stem reservoirs.
4. Restore some of the structural diversity and the river-floodplain linkage of the pre-control channel.
5. Reestablish and enhance native Missouri River fishes and their migrations.
6. Reduce or eliminate major point and nonpoint sources of pollution.

7. Reestablish native terrestrial and wetland plant communities along the river channel and floodplain.

Specific subobjectives to achieve these above objectives are outlined in Galat et al. (1996, 1998) and further expanded in several other specific conservation planning documents (e.g., MDC 1989; USFWS 2013, 2014). In general, the hope is that restoration programs for the Missouri River and its floodplain can be directed toward holistic landscape-level approaches that seek reestablishment of natural functions and community attributes, albeit in a more limited and partly regulated state than during presettlement conditions.

This HGM report provides information specifically focused on identifying options, and subsequent management needs, to restore terrestrial floodplain communities, which specifically embodies objective #7 above. Implicit in restoring floodplain communities is the recognition that restoring some semblance of historical Missouri River seasonal and interannual flow regimes and reestablishing at least some hydrological and ecological connections between the floodplain and the active Missouri River channel is important (see above objectives and discussion of opportunities and constraints in Galat et al. 1988; Sparks et al. 1988; Jacobson et al. 2009, 2011; and others). This report seeks to identify basic landscape attributes for the floodplain that must be considered in restoring the integrity of the LMR ecosystem. The strategic conservation basis inherent in the HGM approach used in this study is scientific information on landscape and floodplain ecology that identifies how the "complex" of communities, rather than the individual parcels, ultimately provides the diversity and distribution (spatial and temporal) of resources needed that historically sustained the productivity, diversity, and integrity of the entire LMR ecosystem.

Based on information gathered in this study, we recommend that conservation actions in the LMR should seek to:

1. Protect and sustain existing floodplain areas that have plant communities similar to presettlement conditions.

2. Restore plant and animal communities in appropriate topographic and geomorphic landscape position.

3. Restore at least some sustainable "patches" of habitats that have been highly destroyed or degraded.

4. Restore habitats and areas that can serve as a "core" of critical, sometimes limiting, resources that can complement and encourage restoration and management on adjacent and regional private lands.

Meeting these goals will require the following general considerations:

1. Protect and sustain existing floodplain areas that have plant communities similar to presettlement conditions.

Essentially all remaining habitats within the LMR are altered to some degree, usually because of changed hydrology; size, connectivity, and interspersion with other habitats; altered and diminished disturbance and regeneration mechanisms; and influences of adjacent lands, especially agricultural and urban uses. Despite alterations, some areas still retain relatively unchanged composition of vegetation communities compared to presettlement periods. These remnant patches, especially areas that contain habitats that have been destroyed at high rates and extent such as bottomland prairie and woodland-savanna, floodplain forest, and bottomland lakes deserve priority for protection. Recent aerial photographs and other maps of the LMR identify remnant habitat and lands that currently are owned and protected by public and private conservation agencies and organizations (except that WRP lands are not identified, see Appendices MS-12, MS-13). Ownership, however, does not always guarantee restoration of historic communities or the management to sustain specific ecosystem types or complexes of historic habitats. All remnant habitats within the LMR (both protected and not protected) should be carefully evaluated to determine if future protection or changes in management are needed. On private lands, acquisition or securing conservation easements may be possible for some remnant patches. For other non-protected sites, discussions should begin with owners to identify conservation opportunities.

Conservation of existing habitat remnants should go beyond simply purchasing lands or securing deed/management restrictions for certain uses. Sustaining existing habitats also requires protecting or restoring the ecological processes that created, and can sustain, the habitat. Often these ecological processes are disturbance events such as flood and drought, fire, and periodic physical disruption of sediments or plant structure (Junk et al. 1989, Poff et al. 1997, Sparks et al. 1998). Unfortunately, most remnant habitats in the LMR have at least some disruption in these ecological "driving" processes, and restoration of most habitats will require at least some active management, whether it be manipulation of water regimes (e.g., periodic drawdowns of bottomland lakes), periodic scouring or disturbance of sediments (e.g., dredging or removal of plugs in side channels or disking in bottomland prairie swales), disturbance of vegetation (e.g., fire or mechanical removal of prairie vegetation or timber management in floodplain forest), or reduction in contaminant inputs from adjacent lands (e.g., construction of silt basins or vegetation buffers along edges of bottomland lakes and other floodplain wetlands – see e.g. Anderson 1980, USACE 1993, Heimann 2001, Blevins 2004).

2. Restore communities in appropriate topographic and geomorphic landscape position.

The historic distribution of vegetation communities in the LMR was determined by regional climate, geomorphic surface, topography and elevation, soils, and hydrologic regime. This report summarizes GLO and ESD information about historical community type and distribution in the LMR and produced an HGM matrix that outlines the abiotic features that are associated with each community/habitat type in LMR reaches. Attempts to restore specific habitat types must "match" the physical attributes of a site with requirements of each community, and not try to "force" a specific habitat type to occur on a site where it cannot be sustained.

This study produced maps of potential natural vegetation (PNV) that could be restored in each LMR reach if community-specific physical conditions (such as soil type, geomorphic surface) and ecological processes (such as appropriate flooding and drying regimes) exist or could be restored (Appendix MS-14). These maps were developed by overlaying the HGM matrix of attributes associated with each major community on contemporary maps of geomorphic landform, soils, topography and elevation, and flood frequency in association with previous attempts to understand basic distributional characteristics of communities from GLO (Appendix MS-10) and ESD (Appendix MS-11) analyses. In cases where GLO and ESD maps were divergent, the fall-back approach for map production was to use HGM matrix Table 2. Other exceptions to prior mapping occurred for some PNV areas as discussed later for each reach.

These PNV maps do not imply or suggest that all areas shown could be restored to historic habitats, but rather they broadly identify which LMR locations have HGM characteristics that potentially could support specific communities. Obviously, many social, political, legal, and economic factors ultimately affect the potential for individual sites to be restored. For many habitats, potential restoration sites essentially mirror historical distribution (Appendices MS-10, MS-11) because these are the only locations that have appropriate geomorphology, soils, and landform characteristics associated with the habitat. For example, bottomland prairie historically was distributed on wide floodplain terraces, higher second bottoms, and sediment mounds on older point bar surfaces; slope forest was always on alluvial fan surfaces with erosional soils; bottomland lakes were in abandoned channels; and riverfront forest was present on young and highly scoured chute and bar surfaces (Weaver 1960, USACE, Nigh and Schroeder 2002, Nelson 2005). Potential restoration sites for other communities such as floodplain forest also basically mirror historic distribution but contemporary potential restoration sites also reflect systemic and local landscape changes. The most obvious change to landscapes that formerly supported floodplain forest is altered hydrology, especially alterations in river-floodplain connectivity and overland water flow patterns along with changed seasonal and long-term hydroperiod and flood frequency caused by extensive levees, ditches, roads, and topography changes.

Clearly, many sites within the LMR now are so highly altered that historical communities cannot be restored on that site. For example, large areas that formerly supported bottomland and mesic prairie now are urbanized and covered with concrete, asphalt, buildings, and roads or they are now highly ditched, leveled, leveed and intensively farmed. In other areas, changes have occurred (e.g., lands protected behind large levees) so that historic hydrological or physical disturbance events cannot occur, however the new condition of these sites may be able to support another system community type (e.g., expanded distribution of floodplain forest behind main stem levees). Current landscape features (e.g. levees, ditches, etc.) and flood frequency-soil wetness data can be used to determine potential contemporary floodplain elevations associated with various flood frequencies throughout the LMR and to understand how current landscapes match the HGM matrix conditions for community establishment (see Appendices MS-6, MS-7; Jacobson et al. 2007, 2011 Chojnacki et al. 2012). Consequently, the maps that show the general locations of potential restoration sites (Appendix MS-14) are useful to make system-wide strategic decisions about where to target restoration activities to restore functional distributions of communities throughout LMR reaches. Specific features that need to be considered at local sites and for each community are presented later in this report. Additionally, a process to identify opportunities and uncertainties about the restoration potential of individual sites is discussed in the "Application of Information (How-To)..." section of this report.

Sustainable restoration of most LMR communities will require a combination of works that includes revegetation (through natural or artificial means), restoring topographical features (e.g., Stratman and Barickman 2000), and recreating basic processes such as flooding, fire, soil disturbance, etc. The degree that landscapes and processes have been altered will influence the difficulty and cost of both restoring and managing the site in the future (Fig. 16). In the LMR, restoration of bottomland and mesic prairie and floodplain forest will be more difficult than restoring riverfront or slope forests. The geomorphic surfaces and fundamental processes that created and maintained prairie (terraces, higher point bars, fire) and floodplain forest (at least less frequent than 5-year overbank flood frequency, mostly non-clay soils) are more highly destroyed and degraded than the topography and processes that sustained riverfront forest (chute and bar coarse sediment sandy-type surfaces that remain connected to Missouri River overflows in batture lands) and slope forest (alluvial fans where upland sheetflow of water drains onto and off of these slopes).

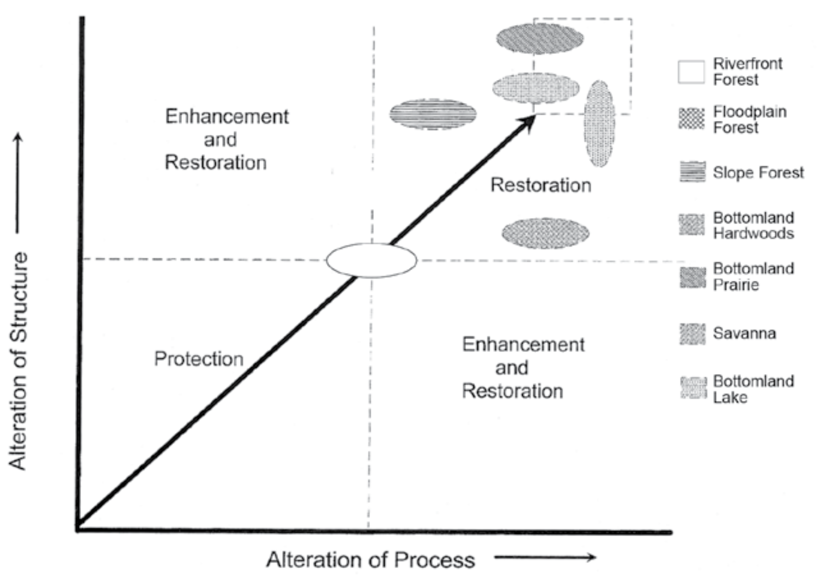


Figure 16. Model of conservation actions most appropriate for, and intensity of management required on, sites of varying amounts of alteration from presettlement condition for major habitat types in the LMR.

3. *Restore at least some sustainable "patches" of habitat types that have been highly degraded or destroyed.*

Several recent documents have identified the loss of presettlement floodplain habitat types in the LMR (see previous Ecosystem Change section). Generally, the most destroyed habitats in the LMR are wet-mesic and wet bottomland prairie (including bottomland prairie-type marshes), floodplain forest, and woodland-savanna communities. Only riverfront forest currently remains in larger contiguous patches that somewhat resemble historic distribution. The diversity and heterogeneity of habitats within the LMR enabled the region to provide critical ecological functions and support diverse and abundant animal populations. Many large spatial "gaps" now exist in the historic distributions of LMR communities (e.g., the nearly nonexistent remnant bottomland and mesic prairie and savanna), remnant habitats are highly fragmented (e.g., small disjunctive patches of floodplain forest), seasonal or long-term connectivity to the Missouri River is reduced or eliminated (e.g., bottomland lakes), and linear habitat and travel corridor connectivity and continuity are reduced or eliminated (e.g., the patchy distribution of floodplain forest).

Where possible, habitats should restored where they can: 1) occur in larger patches, 2) connect remnant or other restored patches, 3) provide physical and hydrological connectivity, 4) emulate natural water regimes and flooding dynamics, and 5) fill critical gaps in former distribution patterns of communities (e.g., Noss and Cooperrider 1994, Shafer 1995, Gurnell 1997, Helzer and Jelinski 1999, Falk et al. 2006). This will be difficult in some locations and for some habitats. For example, formerly expansive continuous prairie in the Missouri-Mississippi River Confluence, middle Kansas Reach and Grand River bottoms, and Platte and Little Sioux reaches have been almost entirely converted to agricultural fields or to urban areas. Despite difficulties, some priority should be given to restoring at least some functional patches of all historic habitats to restore parts of the integrity of the entire LMR.

The annual primary and secondary production of LMR habitats was among the greatest of any ecosystem in North America. This production historically depended on seasonal and long-term flooding regimes and regular fire, wind, and soil disturbances. High primary productivity in the LMR was created by high fertility of alluvial soils (hence the large past conversion to agriculture), a midcontinent climate, and regular inputs of nutrients and sediments from floodwaters of the Missouri River and its tributaries. High secondary production in the LMR was sustained by large inputs of nutrients and plant materials from diverse forest and prairie communities. Protecting and restoring both ecological structure and processes in the LMR ultimately is critical to creating and sustaining rich seasonal pulses of resources in this floodplain system and the many potential foods and ecological niches occupied by diverse fish and wildlife species.

Food webs in big river floodplains are complex and highly seasonal (e.g., Sparks 1995, Heitmeyer et al. 2005). Most animals that historically were abundant in the LMR relied on multiple foods during the year, or they were present only during seasons when specific resources are present (e.g., hard mast, detrital invertebrates, moist-soil seeds, arboreal insects, etc.). A basic adaptation of many of these animals was high mobility and species also relied on connected water flow and habitat patches that enabled them to move throughout the system (e.g. during floods) to exploit resources. In floodplain ecosystems, the connectivity of terrestrial and aquatic habitats is an important aspect of disbursement and distribution of nutrients, water, and energy flow. Maintaining or restoring connectivity of water flow and habitats where possible in the LMR is critical for sustaining "traditions" of use by seasonal animal visitors, securing critical resources to meet annual needs of resident species, and reducing predation or other mortality agents. Restoring connectivity between the Missouri River and the LMR floodplain, at least in some locations, is important, yet will be difficult to achieve in many areas where large flood protection levees exist along the river. Nonetheless, opportunities to reestablish some connectivity, and to emulate natural seasonal and long term hydroperiods, should be pursued (e.g., Hesse and Mestl 1993, Galat and Lipkin 2000).

4. ***Restore habitats that can serve as a "core" of critical, sometimes limiting, resources that can complement and encourage restoration and management on adjacent private lands.***

Ultimately, restoring ecological functions and values of the LMR ecosystem will require conservation and restoration of both public and private lands throughout all reaches. Public lands often can serve as a "core" of resources within floodplains, however they are not always large enough, distributed in all "gap" areas, or contain a diversity of critical habitat types to meet needs for all species. A general goal for "core" conservation areas should be to couple existing or planned public areas with adjacent private lands to create functional complexes of habitats and resources throughout the LMR (e.g., see similar conservation strategies in National Ecological Assessment Team 2006).

The historic diversity of vegetation communities in the LMR assured that many food types were present and abundant in all seasons (Fig. 17). Changes in dis-

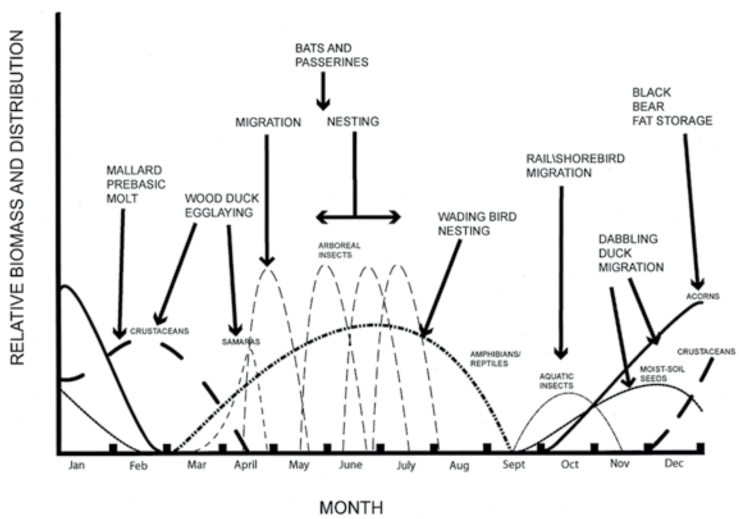


Figure 17. An example of seasonal pulses of food types in floodplain forest and key annual cycle events of select species that coincide with these pulses (modified from Heitmeyer et al. 2005).

tribution and extent of some habitats (e.g. the high percentage loss of prairie, savanna, and floodplain forest) have clearly altered amount and availability of some foods. Where declines in key resources and foods are identified for an area, attempts should be made to either restore that component of the system or replace the resource with another similar type. Managers must recognize, however, that long-term sustainability of animal communities will require restoration of key plant communities in appropriate locations throughout the LMR (Appendix MS-14).

ECOLOGICAL CONSIDERATIONS FOR RESTORATION OF SPECIFIC COMMUNITIES BY REACH

This report does not attempt to prioritize specific sites that can be restored. Opportunities and individual priorities for restoration at a site(s) will depend on many factors including site availability, landowner and conservation objectives, financial options and assistance for landowners, resource agency budgets, mitigation or compensation needs of land or water development projects, commodity and resource markets, etc. While conservation organizations in the LMR may have different objectives and capabilities to restore habitats, the collective and coordinated works of all parties offer the opportunity to restore many parts of the region. In general, the key to restoring some biodiversity, functions, values, and sustainable communities in the LMR is in restoring a mosaic of all habitats in natural distribution patterns and in restoring some semblance of natural hydrology and floodplain water flows in this ecosystem.

This report identifies landscape and ecological characteristics that are needed to successfully restore specific habitats. This HGM process of identifying the matrix characteristics associated with specific habitats (Table 2) is useful in several contexts. For example, the HGM matrix and PNV maps produced in this report help decide what restoration options are most appropriate if: 1) sites are sought to restore specific habitat types including those that are greatly reduced in area and distribution (e.g., prairie), represent a key "gap" in coverage or connectivity (e.g., floodplain forest), provide key resources for animal species of concern (e.g., seasonally flooded prairie cordgrass habitat used by massasauga rattlesnakes), or are needed for mitigation; or 2) a site becomes available or offered to a resource agency and decisions must be made on what habitats can/should be restored on the site given budget, management, and development constraints. The specific HGM characteristics and restoration potential for the major habitat types in each reach are discussed below.

Osage Reach

The potential to restore native vegetation (PNV) in the Osage Reach is best for riverfront and floodplain forest in all areas except for the high terrace mound between the Mississippi and Missouri rivers east of St. Charles, which historically contained a large contiguous band of wet-mesic and bottomland wet prairie along with embedded clay-based marshes and the historic Marias Temp Clair, Marias Croche, and Creve Coeur bottomland lakes (Appendix MS-14). In addition to the historic prairie complex the confluence area also historically supported the largest contiguous band of floodplain forest in the Osage Reach on the braided bar surface north of the Missouri River where soils are relatively well drained silt loams and clay loams. Sandy and gravelly soils that are frequently flooded in the confluence are best suited for riverfront forest, as are other similar areas throughout the entire Osage Reach. The islands of the reach including the larger Pelican, Catfish, Howell, Miller, Goose, Rush, Heckman, Stoner, St. Aubert and Bonhomme islands still retain almost complete coverage by riverfront forest. Floodplain forest only is present on islands where non-sandy soils occur on the very highest elevations > 5-year flood frequency (e.g., Cora Island), and even there contains significant components of early succession cottonwood, sycamore, and willow in part because of frequent and prolonged inundation of high flow events in the past three decades.

The potential to restore prairie in the Osage Reach clearly is best in the confluence area, and the diversity of elevations, soils, and flood frequencies can enable restoration of several interspersed prairie types. The lowest elevations with clay soils generally are best suited for more frequent and prolonged flooding and present unique opportunities to support wet bottomland prairie marsh. The current Marais Temps Clair lakebed that is owned by MDC and an adjacent private duck club is the largest single block of potential marsh habitat, with old sandy plugs on the end of the lake supporting riverfront forest. If management of Marais Temps Clair can emulate natural seasonal and interannual dynamics of flooding and drying, along with control of invasive woody riverfront willow into the old lakebed, the site offers good potential to retain a larger bottomland prairie marsh. Other former prairie areas in the confluence area could be restored to wet-mesic and wet bottomland prairie depending on elevation and flood frequency. Prairie restoration in this confluence band would ideally be on non-clay soils, locations with few dissecting drainages and ditches, and at least 100 acres and preferably at least ¼-mile wide (see Helzer and Jelinski 1999). Further restored areas will require active management with fire, plantings, and perhaps occasional grazing or mowing.

The area south of the Missouri River and north of Hazelwood appears to have historically supported prairie with a possible savanna or slope forest extension onto the Bridgeton/Hazelwood bluff at the time of the GLO surveys and the Lewis and Clark Expedition (Appendix MS-10). This area likely represented an extension of a former point bar at some unknown time (Appendix MS-3) when the river had a more southern course that flowed along the Hazelwood bluff line. Likely this point bar area supported prairie, which was contiguous with the other prairie north of the current river at this time, but this prairie tract became bisected when the river channel shifted north. The soils of this area are mostly silt clay loams that potentially could support prairie today, but its isolated position between the river and bluff and the frequent flooding of some interior areas suggests the best potential today is for floodplain forest.

Another interesting apparently former prairie area that PNV maps indicate is best suited for riverfront and floodplain forest is the Greens Bottom area that occupies higher land between Bonhomme and Catfish islands. It seems likely that a lobe of wet-mesic prairie extended onto this area at the time of the GLO (Appendix MS-10), which represented an extension of upland prairie north towards the St. Charles, St. Peters and the Dardenne Prairie region. A band of slightly higher elevation silt loam is present here, and most of the HGM attributes needed to support prairie are present, except that the site is now surrounded by urban and forested areas, which likely would restrict the use of fire to disturb the site, and the surrounding mostly riverfront forest species likely will continually "seed" the area with the presence of wind-blown willow, cottonwood, and sycamore seeds and would make control of woody invasion a requirement of any attempt to reestablish prairie. Consequently, while this Greens Bottom area is a candidate for restoring prairie, the site would be relatively small and require intensive management to control woody invasion and to attain regular grass disturbance in the probable absence of fire.

If prairie can be restored in the confluence region, it seems possible to also potentially restore some narrow bands of savanna to transitional areas from prairie to adjacent floodplain forest. Mapping of the historic distribution of, and current potential for, savanna is difficult because the distribution of this mix of grass and trees was temporally dynamic and expanded and contracted as flooding and drought cycles occurred in the region. The ecological factors that created savanna historically were the actively competing factors that favored prairie (fire, herbivory, higher sloping elevations) vs. forest or marsh (more frequent flooding, more regular scouring or deposition of sediments, and ponding of surface water for extended periods. As such restoration of savanna in the confluence area will require likely require reestablishment of prairie first and then regular disturbance including fire and mowing. It is interesting that most small remnant patches of savanna in the confluence and nearby Middle Mississippi River ecoregion occur near dwellings or towns, on historic school lands, and at church and cemetery sites on the edges of former prairie sites where some sort of regular disturbance (usually mowing) of grasses and control of tree density has helped maintain the interspersion of grass and trees (Heitmeyer 2008).

Restoration of floodplain forest seems possible and desirable in many areas throughout the Osage Reach in an interspersed pattern with riverfront forest. The key to restoring this diverse and interspersed forest matrix will be to carefully identify sites that have non-sand, gravelly, or clay soils and that have a greater than 5-year flood frequency, including sites now protected from more frequent flooding by mainstem levees. More frequently flooded sites especially those with sand or gravelly soils will encourage highly water tolerant species that dominate riverfront communities. Further, the poorly drained clay soils historically occurred in deeper swales in the floodplain and supported either marsh or shrub/scrub communities. One of the values of restoring floodplain forest to the reach, and throughout the LMR, is the diversity of tree species associated with the community compared to riverfront bands and that some mast-producing trees such as oaks and pecan also are present, which adds an important food source that is absent elsewhere. Restoring riverfront forest in the Osage Reach will probably be the easiest to achieve because nearby sources of seeds for this community are present along the river and on islands already and the more frequent flooding and sandy type soils in the reach are common and widespread.

A few small areas in the Osage Reach likely formerly were slope forest communities and these sites seem prime candidates for restoring this upland-type community. These sites are all alluvial fans along the river bluff where elevations rise rapidly and are above the 100-year flood frequency zone. They include the previously mentioned Bridgeton-Hazelwood bluff, the McKittrick area, near Chamois, and possibly west of Mokane (see discussion in the next Grand River Reach section).

In summary, ecosystem restoration in the Osage Reach could ideally seek:

- more linear connectivity of riverfront forest along the river channel and on current islands.
- interspersion of patches of floodplain forest throughout the reach on higher elevations and non-sand/gravel/clay soils.
- small marsh complexes in deeper floodplain sloughs and swales where clay soils are present.
- restoration and management of the larger Marais Temps Clair, Creve Coeur, and Marais Croche bottomland lakes as floodplain marsh surrounded by riverfront forest.
- restoration of larger patches of wet-mesic and wet bottomland prairie in the high terrace area between the Mississippi and Missouri rivers.
- restoration of slope forest in a few high elevations on alluvial fans next to river bluffs.

The majority of public lands in the Osage Reach are islands or areas immediately adjacent to the Missouri River. Most of these sites have riverfront forest as the primary PNV, although several have larger areas that could be restored to floodplain forest including Columbia Bottoms, Ted and Pat Jones Confluence State Park, Cora Island, Dresser Island, and St. Auberts Island (see an example of restoration planning in this area in McCarty et al. 2004). However, currently few opportunities exist on public lands to restore longer linear corridors of floodplain forest. The only public lands with potential to restore larger prairie or prairie marsh habitats are Marais Temps Clair and the southern higher elevations on the Riverlands Tract. In contrast, many duck clubs in the confluence area have conservation easements and are in prime locations for restoring wet bottomland prairie and marsh habitats.

Grand Reach

The PNV maps for the Grand Reach reflect an extension of the riverfront-floodplain forest complex of the western Osage Reach upstream to about Glasgow (Appendix MS-14). The Grand Reach has a considerable amount of PNV floodplain forest, most of which is in the long bottoms that alternate between the loop bottoms in the middle part of the reach. Loop bottoms that include Marion Bottoms, Plowboy Bend, and the Lisbon Bottom-Jameson Island complex are sites of more recent active river meandering and deposition of coarse sediments that support mainly riverfront forest. The largest potential contiguous blocks of floodplain forest in the reach are the area south and west of Tebbetts, Missouri; the long bottom east of Jefferson City; sections of Overton Bottom; and the long bottom from New Franklin to Jameson Island. Two alluvial/colluvial fan areas historically supported stands of slope forest; these include an area immediately north of Cote Sans Dessein west of Tebbetts and the bluff at Franklin.

PNV prairie habitats begin to occur west and north of Glasgow. Immediately west of Glasgow the large upland prairie formerly in the Marshall to Slater area extended into the Missouri River floodplain south of Epperson Island. This area also contains a clay-based floodplain marsh tract, which is the only substantial clay soil area in the reach; this site should be evaluated as a good potential area to restore floodplain marsh habitat. The most extensive prairie in the Grand Reach is the area north and east of Dalton Cutoff, and while separated by the mostly forested lower Grand River riparian corridor, it essentially represents the eastward extent of the large bottomland prairie complex west of the Grand River in the Kansas Reach (see next reach section). This Dalton Cutoff area prairie contained mostly wet-mesic prairie on the higher elevations, but also had pockets of wet bottomland prairie and marsh. The east extent of this prairie complex appears to be the old Chariton River corridor, although a few areas along the Chariton River floodplain historically may have contained some prairie. ESD maps (Appendix MS-11) suggest a larger prairie complex in the Chariton River confluence area, but GLO maps and survey tree data (Appendix MS-10) clearly show this area contained an abundance of trees including both floodplain and riverfront forest species and the area is frequently inundated. Consequently, it seems the area encompassing the "old natural channel" and now "new channelized" portions of the lower Chariton River area is best suited for riverfront forest with some floodplain forest on higher ridges. The presence of some oaks both here and on the edges of the Dalton Cutoff prairie suggest a band of savanna or more open woodland likely was present; Meriwether Lewis noted: " ...a happy mixture of prairies and groves ..." in the area (Moulton 1988). Similarly, GLO surveys recorded several oaks adjacent to the west Glasgow prairie patch indicating that savanna may have occurred there. GLO maps suggest small prairie patches south of Petersburg, Missouri along the east bluff; however these areas contained many trees including sycamore and some oaks. Further, upland areas next to these sites historically supported upland forest, and it seems unlikely these sites did indeed have sustainable prairie communities.

In summary, ecosystem restoration in the Grand Reach could ideally seek:

- linear connectivity of riverfront forest along the river channel and in several loop bottom areas.
- larger contiguous tracts of floodplain forest in long bottoms, interspersed throughout the reach on higher elevations above the 5-year flow recurrence interval, and on silt or loam type soils.
- restoration of floodplain marsh in the poorly drained clay soil depression west of Glasgow and in deeper floodplain sloughs and swales in the Dalton Cutoff prairie area.
- protection, restoration, and management of the large Dalton Cutoff Lake as a bottomland lake marsh; with riverfront forest adjoining it to the west; and prairie, marsh, and savanna restored to the east and north of it.
- restoration of larger patches of wet-mesic and wet bottomland prairie in the high terrace area northeast of Dalton Cutoff.
- restoration of slope forest in a few high elevations on alluvial fans next to river bluffs.

The Grand Reach contains several public conservation land holdings including both long and loop bottoms. Loop bottoms at Marion Bottoms, Plowboy Bend, and the Lisbon Bottom-Jameson Island complex are best suited for riverfront forest with small inclusions of floodplain forest carefully selected to the highest elevation non-sand soils. In contrast, the large Overton Bottoms and the far north part of Eagle Bluffs CA have good opportunities for supporting floodplain forest. The highest elevations on the northwest side of Smoky Waters CA also seem a candidate for restoring floodplain forest communities. Franklin Island and Diana Bend contain mostly newly accreted coarse sediments that should support riverfront forest species, although a few of the very highest non-sand soil areas on both areas could potentially support floodplain forest species. While no public lands currently exist in the Dalton Cutoff region, the area contains numerous duck clubs and WRP lands. Dalton Cutoff is highly controlled for recreational interests but has degradations from siltation and water diversions (e.g., USACE 1993). Coordinated ownership management of the cutoff seems possible and should seek to emulate both natural seasonal and interannual hydrological dynamics along with maintaining the productive bottomland lake ecosystem. The area adjacent to Dalton Cutoff could also be restored to a substantial complex of diverse forest, savanna, and prairie communities. Many of the WRP lands in the Dalton Bottoms offer excellent potential for restoring both bottomland prairie and marsh habitats.

Kansas Reach

The Kansas Reach offers a striking dichotomy of extensive, mainly PNV forest, immediately adjacent to the Missouri River and west of Sunshine Lake vs. extensive contiguous prairie east of Richmond and the Malta Bend area (Appendix MS-14). Sunshine, Cooley, Teteseau, and Big lakes represent remnant bottomland lakes marshes.

The west Kansas Reach contains the largest contiguous block of PNV floodplain forest in the LMR (Appendix MS-14). This region generally contains the aggraded higher elevation and wider floodplain of the historic Kansas River, which includes widespread point bar and splay geomorphic surfaces (Appendix MS-2). Further east, the floodplain widens and becomes lower elevation where it enters less resistant Pennsylvanian shale and limestone bedrock surfaces. Consequently, the west part of the Kansas Reach is less frequently flooded (Appendix MS-7) while containing extensive areas of well-drained silt loam and silty clay loam soils (Appendices MS-4, MS-5). The GLO survey maps indicate this area was formerly almost completely forested, with exceptions of prairie lobes that entered the floodplain from adjacent upland prairies (Appendix MS-10). Also, GLO tree data indicate a high occurrence of floodplain forest species such as box elder, ash, elm, hackberry, oaks, and others. Riverfront forest in the western Kansas Reach appears to have been confined to sandy-gravelly soils next to the river or adjacent to older abandoned channels such as at Cooley and Sunshine lakes. In contrast, east of Richmond the Kansas Reach contains extensive and wide riverfront forest communities along the Missouri River. Slope forest also occurred in many areas of the west Kansas Reach where very high elevation fan and slope sites merged with the floodplain; many of these slope forest areas have > 200 year flow recurrence interval sites.

The expansive prairie east of Richmond is a dominant feature of the Kansas Reach and represents the largest contiguous floodplain prairie tract in the LMR south of St. Joseph. This prairie area contains a range of PNV mesic prairie on floodplain bench/terrace sites that often are above the 100-year flow recurrence interval area (see Appendix MS-7), to low elevation prairie marshes in clay-based soils. Much of the prairie from Richmond to the Grand River corridor was wet-mesic type with several large embedded wet bottomland prairie patches. One large distinctive PNV clay soil marsh area lies just northeast of Hardin and a few other clay marsh areas occur along Van Meter Ditch east of Malta Bend. Areas of higher elevation in the floodplain northeast of Marshall grade quickly to mesic prairie, which is an extension of the very large prairie system on the Marshall Plain (Nigh and Schroeder 2002). Other historical areas with prairie include small relatively disconnected patches of mostly wet-mesic prairie east of Cooley Lake and south of Atherton and east of Buckner, Missouri along Fire Prairie Creek.

GLO survey notes show few trees in prairie areas except for scattered trees in some north floodplain bluff rise areas. In contrast, the boundary between riverfront or floodplain forest and prairie seems very sharp where riverfront forest narrowly lines the Missouri River channel, is present in parallel bands along the Grand River and Crooked Creek tributary corridors, or represents the marked transition from prairie to forest west of Highway 13 that runs from Lexington to Richmond. This information suggests relatively little savanna historically was present in the Kansas Reach.

In summary, ecosystem restoration in the Kansas Reach could ideally seek:

- more linear connectivity of riverfront forest immediately along the Missouri River channel and along the Grand River and Crooked Creek.
- larger contiguous tracts of floodplain forest west of Highway 13 on higher ridges and silt or loam type soils.
- restoration of a large marsh complex in the clay depression northeast of Hardin and east of Malta Bend.
- protection, restoration, and management of the large Cooley and Sunshine lakes and the smaller Big, Teteseau, and Hardin lakes as bottomland lake marshes.
- restoration of larger patches (> 100 acres, see discussion about prairie patch size and management in the previous Osage Reach section) of wet-mesic and wet bottomland prairie in the high terrace area from Richmond to Brunswick with extensions of mesic prairie onto adjacent upland prairie bluffs.

Public lands in the Kansas Reach are relatively limited, although MDC properties at Grand Pass and Cooley Lake CAs represent larger blocks. Other lands are mostly smaller tracts immediately along the river including river accretion sites at Cranberry, Baltimore, and Jackass bends, which are mainly suited for riverfront forest. Unfortunately, the once expansive prairies in the reach have been almost completely converted to agriculture. Grand Pass CA has been intensively developed and now is a managed wetland complex including most of the historic Teteseau Lake. While originally mostly covered with riverfront forest, the CA did grade quickly to prairie on its south side, and coupled with the historic lake marsh at Teteseau Lake, the clay-based marshes south of Van Meter State Park represented one of the two large marsh areas in the reach. The other northeast of Hardin now is heavily ditched and drained, but represents perhaps the best natural HGM attribute site for a future floodplain marsh complex in the entire LMR. This area and the historic prairie that extends south toward the current Baltimore Bend Unit of Big Muddy

National Fish and Wildlife Refuge could potentially be an excellent complex of the relict ecosystem in the Kansas Reach. Also, a few WRP tracts in the historic prairie areas of the reach offer potential for prairie-marsh complex habitats.

The several larger relict bottomland lakes in the reach are either within CAs (Cooley and Teteseau) or owned and managed by duck clubs (Sunshine and Big). Each of these lakes suffers from loss of adjacent native habitats that buffer the lake and help filter sediment runoff and contaminants to the lakes (with the possible exception to some degree for Teteseau Lake). For example, Sunshine Lake has farm land essentially to the lake banks in many areas. All of these lakes need additional protection, restoration, and management to ensure that they have hydrological regimes that emulate historical seasonal and interannual dynamics and can support productive lake-marsh communities.

Nodaway Reach

The Nodaway Reach has one of the least diverse mixes of PNV communities of any of the LMR reaches (Appendix MS-14). This lack of diversity apparently results from its newer age, incised channel, narrow floodplain, and relatively short length compared to other reaches. The reach also has a preponderance of loop bottoms with newer accreted soils and river meanders from Weston south to Kansas City. This southern part of the Nodaway Reach is dominated by riverfront forest and is frequently inundated. Only two small floodplain depression areas including Dry and Horseshoe lakes south of Farley, Missouri and the Mud Lake area near Stillings, Missouri contain PNV bottomland marsh habitats. North of Weston Bend, the Nodaway Reach remains dominated by riverfront forest but contains the larger Bean, Lewis and Clark, and Contrary lakes and the old and new Mud Lake/Horseshoe lake complex near Kenmoor, Missouri that all represent remnant bottomland lake marsh complexes. A few higher elevation ridges and floodplain edges also have floodplain forest PNV and small extensions of slope forest occur in areas where alluvial fans have eroded onto the floodplain. The only area in the reach that historically may have contained prairie is the higher elevation bench that extends to the floodplain at and immediately south of St. Joseph. GLO maps suggest this to be an extension of the expansive upland prairie that occurred east of St. Joseph (Appendix MS-10, and see Schroeder 1982), but this area now is mostly part of urban St. Joseph with seemingly limited opportunity for restoring PNV prairie.

In summary, ecosystem restoration in the Nodaway Reach could ideally seek:

- more linear connectivity of riverfront forest immediately along the Missouri River channel and throughout the floodplain especially south of Weston Bend.
- interspersed floodplain forest within the floodplain and riverfront forest areas on higher ridges and non-sand soils.
- restoration of bottomland lake marsh habitats at the large Bean, Lewis and Clark lakes and the smaller Horseshoe(s), Mud, and new and old Mud lakes.
- restoration of a few small slope forest patches on alluvial fans.

The Nodaway Reach includes several public conservation lands including Weston Bend State Park , Fort Bend, Dalbey Bottoms, Benedictine Bottoms and Kansas State Penitentiary Farm lands, and Leavenworth Federal Prison Farm lands. Almost all areas on these lands are best suited for riverfront forest PNV with a few minor inclusions of floodplain forest species on higher elevations that are at or above the 5-year flow recurrence interval zone. The Lewis and Clark State Park includes modest restoration potential for the lake and lake edge because it is compromised by recreational development, which makes restoration of dynamic water regimes in the lake less possible. This is also the case at Lake Contrary. Despite challenges, both abandoned channel oxbows could be restored to more productive open water-marsh habitats, surrounded by bands of riverfront forest, if future water management could better emulate naturally occurring seasonal and interannual dynamics. The Bean Lake area, including the MDC Little Bean Marsh area, perhaps is the best remaining opportunity for bottomland marsh restoration and management (Blevins 2004). The several other small bottomland lake marshes including a few WRP tracts seem especially opportune areas to restore marsh areas as well.

Platte Reach

North of St. Joseph, the LMR transitions to a prairie-dominated ecosystem that is bounded by mostly narrow riverfront forest along the Missouri

River and scattered slope forest along the erosional alluvial fans of the eastern loess bluffs (Appendix MS-14). The majority of the Platte Reach is in Missouri and the small areas west of the river in Nebraska historically were covered with riverfront forest except for small areas of prairie west of McKissick Island.

PNV forests in the Platte Reach reflect the marked meandering history of the Missouri River and the associated coarse texture and frequently flooded riparian corridor. GLO survey information suggests these riverfront forests were dominated by dense stands of cottonwood and sycamore (Appendix MS-10). Higher ridges and older remnant natural levees and point bars are less frequently flooded and PNV maps indicate that floodplain forest could potentially be restored on these sites (Appendix MS-14). The GLO data, and some remnant forest stands, suggest that considerable bur oak historically was present on the highest sites, but generally these sites are small and disjunct. The PNV slope forest areas on the east side of the Platte Reach are common south of Squaw Creek NWR and essentially are extensions of loess-type forest and woodland found in areas such as the Monkey Mountain and Riverbreaks CAs. North of Craig, slope forests occur to Council Bluffs, and represent extensions of loess forest such as at the Brickyard Hill CA in Missouri and the Wabonsie State Park in Iowa.

PNV prairie communities in the reach range from a few high elevation mesic types to low bottomland marshes. PNV wet-mesic prairie occupies slightly higher floodplains elevations with 2-5 year flood frequencies, and substantial adjoining areas with 0-2 year flood frequency historically were wet bottomland prairie. Several low clay soil areas also supported bottomland prairie marsh including large areas along the Tarkio River west of Craig and smaller areas near Langdon, west of Watson, and several areas south of Squaw Creek NWR. Big Lake is the largest remnant river oxbow in the reach and historically was surrounded by riverfront forest. The McKissick Island complex represents recent channel dynamics of the area where the Nishnabotna River merges with the Missouri River. GLO survey notes suggest that riverfront forest paralleled both rivers but that prairie extended west from Nebraska into the large point bar that is now McKissick Island (Appendix MS-10). When the Missouri River shifted west to its present position this point bar area was cutoff and likely was originally prairie along with the prairie area north of Auburn, Nebraska. Both former areas now are intensively farmed and it is uncertain if they could be restored to prairie or would naturally be more likely to succeed to riverfront forest should agriculture be discontinued here. Another smaller remnant bottomland lake is present at Forneys Lake near Thurman, Iowa.

In summary, ecosystem restoration in the Platte Reach could ideally seek:

- linear connectivity of riverfront forest along the immediate Missouri River channel and tributary corridors that cross the floodplain.
- small patches of floodplain forest interspersed within riverfront forest stands in the floodplain on higher elevations and non-sand soils. These patches seem likely to support considerable bur oak.
- restoration of a more sustainable bottomland lake marsh at Big Lake. This restoration will require water level management to emulate natural season and interannual dynamics including periodic drawdowns. The extensive development around Big Lake likely will compromise prolonged drawdowns, and a long-term strategic water management plan for the lake will need to be developed.
- restoration of several small slope forest patches on alluvial fans that adjoin the eastern loess hills.
- restoration of larger patches of heterogeneous wet-mesic to wet bottomland prairie marsh throughout the reach including several sites of larger marsh complexes on clay-type soils.

The Platte Reach contains many public lands and the region also includes many smaller WRP tracts along with several duck club properties near Squaw Creek NWR. Areas along the river that include islands and recent point bar bends are best suited for riverfront forest, although the Bob Brown and Thurnau CAs in Missouri currently include wetland units that are intensively managed for herbaceous marsh communities despite sandier soils. The best water retention sites on these two CAs are where lenses of clay loam soil occurs. The many other public areas along the river include Deroin Bend, Indian Cave State Park, Landon Bend, Nishnabotna River Mouth, Upper and Lower Hamburg Bend, Copeland Bend, Auldon Bend, Tobacco Bend, and the Randall W. Schilling area. Collectively, the Bob Brown through the Schilling Area, and then upstream to Deer Island in the Little Sioux Reach (see next section), represents one of the best closely located continuous strings of remnant and currently protected PNV riverfront forest communities in the entire LMR. In contrast, the once vast prairies within the Platte Reach are almost completely converted to agriculture with the exception of the Squaw Creek NWR and some nearby duck clubs. Current management of Squaw Creek NWR has emphasized semipermanent herbaceous and emergent marsh (USFWS 2005), but PNV information (Appendix MS-14) suggests that the refuge could potentially support and/or restore a relatively large wet bottomland prairie. Similarly, many of the duck clubs in the region offer excellent potential to restore wet bottomland prairie and marsh habitats.

Little Sioux Reach

PNV communities for the Little Sioux Reach generally reflect a similar HGM context as the Platte Reach but with generally higher, less flood prone, elevations (Appendix MS-14). The many river loop bend areas in the recent meander belt contain many abandoned channels (both newer and older), coarse texture sediments, and regular inundation frequency. These sites historically were, and currently contain, remnant tracts of riverfront forest. Flood frequency decreases toward the north part of the reach and the higher elevations, mainly on the inside-bend point bars, have areas that contain PNV floodplain forest. Many of these floodplain sites historically supported scattered patches of bur oak and generally less abundant and diverse species composition compared to floodplain forests further south in the LMR. These floodplain forests also historically contained widespread cottonwood, often in an open "gallery-type" distribution (Aikman 1926, Weaver 1960). A few slope areas are present in the reach, but they are less abundant than in the Platte Reach and are mainly east of Council Bluffs and Mordiman, Iowa. Other rapidly rising and alluvial fan areas on the edges of the Little Sioux Reach, with greater than 100-year flow recurrence interval elevations are PNV mesic prairie (Appendix MS-14).

Prairie areas occupied wide continuous bands of the Little Sioux floodplain away from the immediate river and tributary corridors. GLO data suggest rather sharp divisions between riparian forest and prairie communities, and savanna seems to have been narrow bands along some prairie areas, if it existed at all. The most probable savanna locations likely were forest-prairie transition points adjacent to older abandoned channel locations that are further from the current active river meander belt. PNV maps suggest a diversity of mesic to wet bottomland prairie habitats in the reach, with a few embedded marshes where clay soils occurred in the deepest depressions. Bottomland lake communities also were present in the larger DeSoto, Manawa, Horseshoe, Nobles, and Soldier Round Lake areas. Several higher elevation benches with > 100-year flood frequency are present along the edges of the Little Sioux Reach especially north of Blair, Nebraska and Missouri Valley, Iowa. These benches contain variable often erosional-type soils and appear to have historically contained mesic upland prairie that were essentially extensions of the Great Plains upland prairies that adjoined the Missouri River floodplain both in Nebraska and Iowa (Weaver and Fitzpatrick 1934, Weaver 1960).

In summary, ecosystem restoration in the Little Sioux Reach could ideally seek:

- more linear connectivity of riverfront forest along the immediate Missouri River channel and tributary corridors that cross the floodplain.
- patches of floodplain forest interspersed within riverfront forest stands in the floodplain on higher elevations and non-sand soils. These patches seem likely to support considerable bur oak and contain cottonwood gallery distribution if restoration can provide water-soil disturbances required for cottonwood regeneration (e.g., Dixon et al. 2010).
- restoration bottomland lake marsh habitats in remnant abandoned channel lakes and deeper remnant floodplain sloughs.
- restoration of a few small slope forest patches on alluvial fans that adjoin the eastern loess hills.
- restoration of larger patches of heterogeneous wet-mesic to wet bottomland prairie marsh throughout the reach including several sites of larger marsh complexes on clay-type soils.
- restoration of linear corridors of mesic prairie on high elevation benches that adjoin and merge into the floodplain north of Blair and Missouri Valley.

As with the Platte Reach, several public land holdings exist along the Missouri River in the Little

Sioux Reach. South of Omaha the Gifford Bend and Mary's Island areas are classic riverfront forest PNV sites along the river. Just north of Omaha, the complex of Boyer Chute and DeSoto NWRs and the adjacent Wilson Island State Park protect a large block of riparian forest habitat and the large remnant oxbow of DeSoto Lake. These areas are primarily PNV riverfront forest communities but each has inclusions of higher elevation loam soils that historically supported floodplain forest species such as bur oak. Floodplain swale areas on DeSoto and Boyer Chute NWRs also appear to have historically been marsh-type habitats that flooded annually to some degree in most years. North of DeSoto a string of small protected public land tracts is present at almost every river bend, with the larger ones being Tyler and Deer Islands; these are also PNV riverfront forest sites. A few small scattered IDNR tracts occur in former prairie areas north of DeSoto NWR and at Round Soldier Lake. These sites all offer potential to restore several prairie habitat types, especially if they could be expanded in size to create larger more sustainable tracts.

CONSIDERATIONS FOR A "LANDSCAPE-SCALE" LMR ECOSYSTEM CONSERVATION/RESTORATION VISION

The historic LMR represents a large river system that connects and transcends: 1) Great Plains upland prairie, 2) glaciated Central Dissected Till Plains, 3) the northern edge of the Ozark Highlands, and 4) the Mississippi River Alluvial Basin. As a major corridor of water and community resources across these diverse ecosystems, the Missouri River and its floodplain is in effect a primary conduit or connector for fish and wildlife species and supports a myriad of ecological functions and values for the west central North America. A future vision for the LMR should capture this unique landscape position and ecological values.

This HGM evaluation for the LMR attempted to collate the many diverse datasets and analyses of key system-level attributes that determine the structure, function, and attributes of the Missouri River ecosystem including geomorphology, soils, topography and elevation, hydrological regimes, and community type and distribution. Of these HGM datasets, only complete mapping of geomorphic surfaces is unavailable for the entire reach. The capability of integrating these nearly complete HGM data sets has for the first time allowed a true system-level view of past vs. present floodplain communities in the region and the presentation of PNV maps that can be used to guide future conservation and restoration efforts for the region. This PNV capacity enables better understanding of not only current conservation land position and appropriate community type, but also an understanding of how historical communities were arrayed and their ecological continuity that enabled the LMR to be among the most productive ecosystems in North America. The next section in this report provides a "How-To" about this PNV information to assist resource managers in making decisions about appropriate restoration and management at a specific site, and facilitate strategic planning to pursue opportunities to fill gaps in the river floodplain corridor for community types that have been highly destroyed; fragmented; and reduced in scale, size, and connectivity. This latter strategic planning opportunity is an exciting chance to formulate a true ecosystem vision for the LMR in today's real world of alteration and divergent land and water uses and motivations.

This HGM report suggests the following points for consideration of this landscape vision for the LMR:

1. The LMR historically contained a nearly continual riparian corridor of riverfront forest on each side of the river channel from the Little Sioux River to the Mississippi-Missouri River Confluence. Only the western Kansas Reach, which contains mostly PNV floodplain forest, does not have extensive riverfront forest along the Missouri River. In only a few places did prairie extend directly to the river channel and in these locations it represented a site where a recent river meander cut through an older and higher elevation prairie-dominated floodplain terrace. The nearly continual parallel corridor of forest provided an ecological buffer to both the river channel and floodplain, and provided resources readily accessed by river species during annual river rises and floods, and to floodplain species that traveled to the river or along it. For example, this riverfront corridor provided critical foraging resources to river fishes during spring river rises and also was a phenomenal source of food and nesting cover for migrant Neotropical birds (Smith 1996, Galat et al. 2005). While many areas of

riverfront forest remain present in the LMR, many have altered composition, especially an absence of sustainable cottonwood size diversity and regeneration. Attempts should be made to protect and restore a more continual, closely positioned, string of riverfront tracts along the Missouri River throughout the LMR and restore mechanisms for cottonwood regeneration if possible. A good example of such positioning of riverfront tracts is the multiple public land holdings from just north of St. Joseph all the way to the Little Sioux (see discussion in the preceding Platte and Little Sioux Reach PNV sections).

2. The LMR floodplain from St. Joseph south through the western part of the Kansas Reach to about Richmond historically was an unbroken corridor of forest. In effect this river stretch represented a transitional "gateway" for river and floodplain species between prairies to the north to forests in the south. For migrant birds, it was a final large forest stopover area before moving north to prairie, and it also was a northern forest breeding site for some species. The resources obtained by birds (and other north moving species of fish and wildlife) here were critical to build or maintain nutrient reserves subsequently used for reproduction. Likewise, animals moving south first encountered larger and more diverse forest resources in this river stretch after they left northern prairie areas and they began the transition to non-prairie resources they would rely on throughout the subsequent winter and parts of the following spring. Future conservation efforts should seek to protect and restore larger tracts of forest in this area if possible and include the unique regional diversity and landscape position of riverfront, floodplain, and slope forests.

3. Similar to the Nodaway and western Kansas Reach, the area from St. Charles to Glasgow historically was mostly an unbroken bluff-to-bluff forest. The Osage and Grand Reach floodplains contained significant interspersed patches of floodplain forest, especially in the long bottoms that alternated between the tightly meandering loop bottoms. This greater interspersion of floodplain forest species enabled these southeast regions to effectively merge the river floodplain with the Ozark Highlands to the south and the Mississippi Alluvial Valley to the southeast. As such, migrant birds associated with southeastern forests found transitional resources as they moved either north in spring or south in winter. Further, the floodplain forest interspersion added ecological complexity to support the many ecological niches found in the lower Missouri River Valley. Unfortunately, most of the higher elevation sites in the LMR floodplain that formerly supported floodplain forest in the western Kansas, Grand, and Osage reaches (and other floodplain forest patches in northern LMR areas also) have been cleared and converted to agriculture or other uses. Future conservation strategies in the LMR, especially the western Kansas, Grand, and Osage Reaches should seek to protect and restore areas where floodplain forest can be restored in larger patches that connect and/or are interspersed with the riverfront forests along the river channel. Such areas are especially absent in the Osage Reach. One good example of opportunity area now in protection status is the long bottom at the Overton Bottoms NWR unit.

4. Small patches of floodplain forest species, especially bur oak, occurred on higher, less frequently flooded ridges in and next to riverfront forest corridors in the Platte and Little Sioux Reaches. Few of these oak areas remain, but identifying sites that could potentially be restored to bur oak and other floodplain species should be a priority. An example of small potential bur oak restoration occurs in the Bowyer Chute-Wilsons Island-DeSoto complex.

5. The most destroyed part of the LMR floodplain ecosystem is the once expansive prairies (with some savanna fringes) north of St. Joseph, in the eastern Kansas Reach to the Chariton River, and in the Mississippi-Missouri River Confluence area. GLO surveys indicate that a few other small patches of prairie historically may have been present in the LMR (Appendix MS-10), but they were very small lobes that extended from upland prairies in areas away from the above three large prairie tracts. Each of the three large prairie complexes in the LMR included community continuums from upland mesic to wet bottomland prairie. The continuums of these prairie areas in the LMR floodplain added significant diversity of niches and species to the Central U.S. prairie ecosystem

and effectively merged the floodplain with the uplands in these areas. Understandably, historic mesic and wet-mesic prairie areas were among the first areas to be converted to agriculture in many LMR areas because of their open nature, higher elevation, and productive loam-dominated soils. Lower elevation wet bottomland prairies were harder to drain and farm because of their clay soils and frequent inundation, sometimes for prolonged periods. Nonetheless, bottomland prairie and associated prairie marshes eventually also were mostly destroyed as the Missouri River became altered; the floodplain was disconnected from the river; and ditches, levees, and roads destroyed or degraded water flow patterns and hydrological conditions in these areas.

Restoration of prairie in the LMR will be challenging because of their almost complete destruction, competition from agriculture, and land costs. Despite these challenges, the historical ecological integrity, diversity, and values of the LMR will remain incomplete unless at least some large patches and some semblance of a connected network of floodplain prairies are restored. To date, only small fragmented areas in western Iowa, sites on the Squaw Creek NWR and surrounding duck clubs, WRP tracts around Dalton Cutoff and in the Wakenda Bottoms, and private hunting lands in the Missouri-Mississippi River Confluence have retained or attempted any restoration or management of historic prairies. Several other areas also have managed some tracts for bottomland marshes mostly around remnant bottomland lakes (such as the Little Bean Marsh, Marais Temps Clair, Grand Pass, and Cooley Lake CAs) and near the river (e.g., the Bob Brown CA). The key to sustaining bottomland marshes in these areas, however, is in matching wetland sites to appropriate clay-based soils that are poorly drained and not trying to "force" wetlands and water retention in sites that historically contained coarse well drained sediments and that are really riverfront forest PNV areas.

Many areas in the three large historic LMR prairie tracts seem to offer excellent opportunities for prairie, and some savanna, restoration. In particular, areas with extensive complexes of loam-to-clay soils and diverse elevations where wet-mesic to bottomland marsh could be restored include:

- the floodplain north of Blair, Nebraska.
- sites north of DeSoto NWR in western Iowa.
- Squaw Creek NWR and lands north and west past Craig, Missouri.
- the area from east of Hardin, Missouri south to Baltimore Bend.
- the Wakenda River bottoms in the eastern Kansas Reach.
- sites south and east of Dalton Cutoff.
- St. Charles duck club lands south and east of Marais Temps Clair.

Restoration of historical small remnant prairie tracts in other LMR areas seems more difficult and their small sizes and surrounding forest or urban areas will compromise long-term sustainability and would require intensive management if prairie restoration is attempted.

6. The LMR contains several alluvial-colluvial fans with higher elevations on the edge of the floodplain where upland soils have eroded onto the floodplain. These sites historically supported either upland-type mesic prairie or slope forest. In northern areas, both prairie and loess-type slope forest occur, while in southern and eastern areas these fans are essentially extensions of upland hardwood forests. Both mesic prairie and slope forest communities added important community diversity to the LMR, and sites where these communities could be restored should be evaluated and pursued. Certain of these fan sites are small and may be adjacent to already protected sites, which could facilitate their restoration.

7. The frequently, and widely, meandering Missouri River channel created an abundance of abandoned channel oxbows and sloughs throughout the LMR. As mentioned under #5 above, most of these abandoned channel lakes gradually filled with fine clay-based sediments and historically supported open water-marsh habitats adjoined by riverfront forest where coarse sediments plugged the ends of the cutoff channels or lined old river channel natural

levees. Many larger and smaller abandoned channel habitats remain in the LMR, and vary in age from a relatively recent cutoff (e.g., DeSoto, Dalton, Cooley) to an older one (Creve Coeur, Round Soldier). Unfortunately, most remaining bottomland lakes and larger cutoff remnant sloughs are highly degraded today from siltation and other contaminants, eutrophication, removal of buffer vegetation along lake shores, development and urban expansion, and altered vegetation communities (e.g., USACE 1993, Bowan 2006). Future management of remnant bottomland lakes is highly desirable within the LMR, but because of the extensive alterations, will require intensive management, especially a return to more natural water regimes of alternating seasonal and interannual flooding and drying (see also Raedeke et al. 2003). Clearly, the social and economic costs of restoring more natural water and vegetation dynamics to these lakes will be challenging given the many interests, ownerships, and developments involved. Nonetheless, restoration of these lakes should be of high priority to the LMR because of their unique features and resources. Examples of more integrated management strategies for these lakes include those at Marais Temps Clair, Dalton Cutoff, Cooley Lake, Bean Lake, and DeSoto.

In conclusion, if the above seven major ecosystem restoration concepts could be pursued, the LMR could begin to improve its ecological integrity and character of what was once a true ecological gem in North America.

Karen Kyle

Karen Kyle

APPLICATION OF INFORMATION (HOW-TO) FROM THIS REPORT

This report used the basic principles of HGM methodology to evaluate landscape-scale options for restoration of ecosystems in the LMR. The HGM process helps address four basic questions that can guide decisions about what communities can/should be restored at spatial scales ranging from broad ecoregions and regional floodplain corridors to specific tracts of land. The four questions are:

1. What was the historic (presettlement) community, what landscape features were associated with this community, and what abiotic and biotic mechanisms sustained it?
2. What changes have occurred from the historic conditions, both in physical structure and ecological processes.
3. What potential communities can be restored and sustained on the site or region now? In other words, what is the "new desired state" or PNV?
4. What physical and biological changes are needed to create and sustain the new desired community?

Information in this report provides most, but not all, of the answers to these questions to help conservation planners in the LMR make restoration decisions. At a broad landscape scale, this report identifies the historic types and distribution of communities in the LMR (e.g., Appendices MS-10, MS-11) and the current land cover and conservation lands (Appendices MS-12, MS-13) and suggestions on the current suitability of areas for restoring community types (report text, Table 2, Appendix MS-14). This regional information can be used by conservation partners to understand which communities have experienced the largest declines in the LMR and where they may wish to work to restore basic parts of the LMR ecosystem.

At the site-specific scale, this report provides much of the information needed to determine what communities potentially could be restored at a site. For example, the digital GIS databases assembled for this report provide detailed information on the geomorphology, soils, and to some degree the topography and current flood frequency elevations of a site. This GIS information now is available to all conservation organizations and can be sorted and analyzed at any spatial scale. The development of the HGM community matrix in this report (Table 2) can help planners identify what physical features and ecological processes sustained historic communities at a site, and that must be present if the community is to be restored. This report cannot identify all of the physical or biological changes that have occurred at each site in the LMR, but it does describe the general types of landscape alterations that must be identified before decisions can be made about restoration options.

The following sequence of questions may be helpful for determining the best restoration potential for specific LMR sites:

1. Ask what the historic community types were on the site. This is provided in Appendices MS-10, MS-11.
2. Ask what the physical and biological features of the community were and what the controlling biological mechanisms were. This is provided in the text description of communities and in Table 3.
3. Ask what changes have occurred to the site. Some of this information is provided in Appen-

dices MS-12, MS-13 (where existing habitats are) and general information about ecological effects of various landscape changes is provided in tables, figures and text of the report. Obtaining information about detailed changes in landform, hydrology, and community composition usually will require site-specific investigations.

4. Ask what communities are appropriate and ultimately can be sustained for the site given current alterations. The suggestions for general community restoration on sites are provided in Appendix MS-14. In some areas, more than one community type may occur, such as in tributary fan, ridge-and-swale, and tributary floodplain areas. For these sites specific information will be required about elevation and flood frequency to determine the new desired state and detailed distribution of species within the site.

5. Ask what physical and biological changes will be needed to restore the desired community.

The degree that more detailed site-specific information will be needed at any site depends on what information exists for that site. The most common data deficiency for sites within the LMR is the degree of alteration of former hydrology caused by site changes (e.g., levees, ditches, roads) and systemic alterations (e.g. dam and channel effects upstream) often is uncertain. Despite some gaps and uncertainties, this report provides the basic information and tools to plan regional conservation and restoration actions in the LMR and to conduct much of site-specific evaluations. Undoubtedly, some refinement of predicted communities, both past and future, will occur as new information is acquired and existing data are refined.

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MONITORING AND EVALUATION

The future success of community restoration in the LMR depends not only on the first requisite step of identifying the appropriate locations for restoration works in the contemporary or future planned region, but also on regular monitoring and evaluation of ecosystem-wide and site-specific HGM attributes that will influence the suitability and sustainability of the area for such restoration. Also, undoubtedly, new and improved information hopefully will become available to refine and update the HGM matrix of community relationships (Table 2) and PNV maps (Appendix MS-14), and therefore the predictive success in identifying restoration sites for all community types.

This HGM report provides information about critical landscape attributes and processes that will need to be incorporated into restoration plans within the LMR. However, some uncertainty exists about the short- and long-term ecosystem effects of some current land and water uses. Consequently, future restoration efforts that incorporate recommendations in this report should be done in an adaptive management framework where: 1) predictions about community restoration are made and then 2) follow-up systematic monitoring and evaluation are implemented to measure ecosystem responses to various management actions and to suggest future changes or strategies based on the monitoring data. Specific ecosystem attributes that require additional investigation and monitoring/evaluation are provided below:

HYDROLOGICAL REGIMES

Additional hydrological analyses likely will be needed for site-specific planning, especially if USACE water management in upriver impoundments is changed, main stem levees are modified or removed, and channel form and maintenance is modified. In all of these scenarios, suggested changes have the potential to change water depth, duration, and timing for floodplain and channel areas and connectivity. In addition to surface water monitoring, more data are needed about subsurface/groundwater levels in non-impounded areas. For example, the success of restoring floodplain forest will depend on having sites with regular summer-early fall drying windows that dewater soil surfaces and the upper parts of tree root zones. These groundwater data also are important for understanding species composition, and invasive species expansion, in other habitats especially sites that are subject to reed canary grass invasion. Water quality measurements also are needed for restoration sites, especially siltation and contamination levels.

LONG-TERM VEGETATION CHANGES

Certain evidence indicates that remnant native terrestrial vegetation communities in the LMR are continuing to have long-term changes in species composition. Past studies of specific vegetation types and areas have been important to document community changes in the LMR and to understand/predict future changes (e.g., Weaver 1960, Mazourek et al. 1999, Thogmartin et al. 2009, Struckoff et al. 2011). Unfortunately, for some communities, the trend is toward less diversity and more monotypic stands of more early succession and water tolerant species. Also, as indicated, invasive and exotic plant species now have expanded in some habitats and locations. Continued monitoring and systematic inventory of remnant, and future restored, communities is needed to determine sustainability of community diversity and historic composition and the resource functions and values provided by this diversity. This information also will feed-back into understanding of HGM-community relationships and refine definition of the best potential restoration sites and management actions that will be needed to restore and maintain the ecological processes that sustain the community and entire LMR ecosystem.

RESTORATION TECHNIQUES

Restoration of LMR community types likely will occur using many techniques, both site-specific and more systemic . For example, restoration of floodplain forest types could use direct seeding, planting bare root or root-production method (RPM) stock, and/or natural seed rain and restocking from adjacent forests. Also, forest restoration might use weed or animal control to reduce competition or browsing on seedlings. Some topographic or hydrological modification might be used to change flooding duration and timing and soil surface suitability (e.g., Stratman and Barickman 2000). Restoration of other communities also likely will require multiple approaches and techniques that will require monitoring to determine the efficiency and effectiveness of the technique in relation to cost-benefits, desired results, and public expectations. In another example, many lower elevation areas of the LMR that are subject to occasional seasonal flooding influences have become heavily invaded by reed canary grass.

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APPENDICES

INTRODUCTION

Hydro-Climatic Data Network (HCDN) data were used to assess surface water quantity patterns in the LMR. The HCDN is a network of USGS stream gages located within relatively undisturbed watersheds, which are appropriate for evaluating trends in hydrology and climate that are affecting flow conditions (Slack and Landwehr 1992). This network attempts to illustrate hydrologic conditions without the confounding factors of direct water manipulation and land use changes. HCDN trends have identified climatic changes that have contributed to hydrologic patterns in reaches upstream of the confluence with the Kansas River, but no clear hydro-climate changes were identified in the lower region of the LMR. A select few HCDN gages located near the main stem of the Missouri River were used in this evaluation.

Evaluations of various climate teleconnections also suggested evidence for future changes in climate scenarios. The North Atlantic Oscillation (NAO) is a climate teleconnection, which is calculated from the atmospheric pressure differential between dipoles located at the Azores and Iceland. Within the study reaches of the LMR, NAO indices from 1980-2010 are primarily negatively correlated with summer precipitation as a percent of normal, suggesting a future climate scenario of greater precipitation within the basin downstream of Logan, Iowa. Many areas of the LMR also demonstrated a weak negative correlation between the Southern Oscillation Index (SOI) climate teleconnection and total precipitation. Extreme positives and negatives in the SOI are commonly known as El Niño and La Niña, which are opposite phases of the El Niño-Southern Oscillation (ENSO) cycle. The ENSO cycle describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific. The negative trends identified in the LMR suggests that this region is somewhat more likely to respond to El Niño events with higher than average precipitation, though normal and lower than average precipitation rates following El Niño years are still common.

CLIMATE AND HYDROLOGY TRENDS BY LMR REACH

LITTLE SIOUX REACH

Climate - The Little Sioux Reach typically experiences a growing season between 200 and 225 days (FAO 2007). At Omaha, mean annual precipitation is 31.7 inches, occurring on average in a unimodal seasonal pattern of lows in winter increasing to peaks in May and June (Appendix A). On average, this reach experiences 73 days per year with measurable precipitation, though in recent years precipitation has been more common. Snow averages about 26 inches annually. Mean temperature in January is 32 degrees F and rises to peaks in July of about 85 degrees F. Average temperatures are generally cooler in this reach compared to the downstream reaches, with an average annual temperature of roughly 49 degrees F, which is about four degrees cooler than those recorded at other climate stations. Class A pan evaporation averages 60 inches/year with 74% occurring from May to October.

PDSI data from the east-central Nebraska (25-06) and west-central Iowa (13-04) U.S. Climatological Divisions from 1895 to the present suggest that dry climate runs in about 10-year alterations with wetter conditions, with severe drought occurring at about 20-year intervals (Appendix B2a,b; National Oceanic and Atmospheric Administration (NOAA) 2011). Similarly, total water year precipitation at Logan, Iowa suggests alternating dry vs. wet conditions over time that corresponds to roughly the same years as the PDSI data (Appendix B2c).

During the period of record from the early 1900s to the present, climate near Logan, IA has gradually changed with the following trends being evident:

- Yearly precipitation amount has trended higher as has precipitation frequency and intensity (e.g., Appendix B2c, Groisman et al. 2005). Precipitation in the 10 wettest days of the year has increased as the number of severe thunderstorms within 5-year periods. A 27% increase in days with heavy precipitation has occurred from 1958 to 2007, with most of the increase as rain vs. snow. The rising trend in precipitation is most dramatic in summer, spring and fall.
- Mean annual temperatures have increased. Winter and spring temperatures have increased the most over time, but no trends are apparent for summer and fall.
- NAO indices from 1980-2010 are negatively correlated with summer precipitation as a percent of normal, suggesting a future climate scenario of greater precipitation.
- A weak negative correlation between SOI and average water year precipitation as a percent of normal at this station also suggests the area may respond to El Nino events with higher than average precipitation.
- HCDN gages on the Little Sioux and Boyer rivers show recent increases in average annual discharge and increase in variability of the data (1900s-2013), and statistically significant increases in average annual discharge (1936-2013), suggesting that trends in streams in this region could be functions of multiple anthropogenic factors as well as hydro-climate changes in the area.

Hydrology – Larger Missouri River tributaries within the Little Sioux Reach include the Little Sioux, Solider, and Boyer rivers, which all drain portions of western Iowa. With a combined drainage area of approximately 4,800 square miles, these tributaries comprise most of the 6,320 square mile drainage area of this reach (USACE 2004b). The drainage area contribution of this reach is relatively small (two percent of entire upstream drainage area), although it is a significant portion of the unregulated drainage area between the Platte River confluence and Gavins Point Dam. Regardless, flow dynamics through this reach are still largely driven by the drainage area above Gavins Point and, to a lesser degree, by the larger tributaries of the Big Sioux, James and Vermillion Rivers, which enter from the left bank upstream of this reach. Major flood peaks on the main stem through this reach do not correlate with major flood peaks on local tributaries (such as the historic 2014 flood event on the Big Sioux River), which is likely due to a regulatory reduction in main stem dam releases in order to abate any downstream flooding. Through this manner, the main stem dam network not only controls flow dynamics from the upper watershed but also influences the variability experienced through tributary flooding in these upper reaches of the lower river.

The current hydrology of this reach is highly influenced by upstream dam regulation (Appendix B2d-g). During the dry period from the 1930s-1940, average annual streamflow at Omaha responded with record-low levels compared to other pre-regulation data. Conditions became wetter until 1950 and streamflow responded accordingly, but soon the climate alternated to another drought later in the 1950s. Main stem flow regulations began during this transition from a wet to dry cycle. After these alterations, average annual discharge continued responding to wet and dry cycles, however streamflow responses to dry cycles became slightly more consistent (i.e., low-flow years reflected similar levels, clearly higher than pre-regulation drought levels, regardless of drought magnitude) based on average annual discharge data from Sioux City. This effect is not as apparent downstream near Omaha, where average low flow periods are of similar average magnitude pre- and post-regulation, and post-regulation lows are somewhat more variable.

Prior to the main stem alterations in 1954, high-magnitude floods were also much more common. Nine of the 10 highest-magnitude annual peak flows on record at Omaha occurred between the pre-regulation period of 1929-1954, and similar patterns were demonstrated upstream at Sioux City. Daily discharge data shows current 100-year flood occurring roughly every 10 years prior to reservoir development, and lower-magnitude floods also occurred much more frequently.

Near Omaha, the water table is roughly 6-10 feet below the floodplain surface and typically peaks in late May to early June, or one month after peak Missouri River flows (Newman et al. 2014). Groundwater levels are usually at their lowest between December and February.

PLATTE REACH

Climate - The Platte Reach has an average growing season of 225-245 days (FAO 2007). Temperatures range from an average annual minimum of 40.8 degrees F to an average annual maximum of 63.3 degrees F, with a mean annual temp of 52 degrees F (1950-2014) (Appendix A). This area experiences roughly 87 days per year of measurable precipitation and 33.3 inches of rain annually on average (Menne et al. 2012).

PDSI data from climate divisions 13-07 and 25-09 reflect patterns similar to those identified upstream, with 10-year alternations of wet/dry conditions, and severe drought occurring at about 20-year intervals (Appendix B3a,b). Recent droughts have reached relatively low magnitudes compared to droughts that occurred prior to the 1960s. Total water year precipitation at Auburn, Nebraska also shows total precipitation averages fluctuating at roughly the same frequencies (Appendix B3c).

The following climate change trends have been evident from the 1900s in this reach, based on USHCN data from Menne et al (2012):

- An increase in magnitude of extreme precipitation events since the 1990s, based on data from 1975.
- A slight decrease in average precipitation for August and September (1975-2013).
- Average monthly temperatures are typically highest in July or August and coolest in December or January. Average annual mean and minimum temperatures have experienced a statistically significant increase (1900-2013), with the most dramatic rise occurring since the 1960s. In particular, average, mean, and minimum spring temperatures, as well as minimum and mean summer temperatures (1950-2013) have increased significantly, suggesting an increase in nighttime humidity.
- Between 1975 and 2013, average monthly temperature increases have been the most dramatic between late winter through early spring (January-March), suggesting milder winter conditions and an earlier spring thaw. This is also supported by a statistically significant decrease in the number of days per year with minimum temperatures below 0°F (1975-2014).
- A weak negative correlation between SOI and average water year precipitation as a percent of normal at this station also suggests the area may respond to future El Nino events with higher than average precipitation.
- An HDCN gage on the Tarkio River offers evidence of a long term change in the regional hydrology as a result of climate change on top of other anthropogenic influences such as flow regulation or

land use changes. The longest continuous dataset recorded at this gage (1923-1990) demonstrates a statistically significant increase in the average annual water year discharge (*p*=0.01), suggesting that the Tarkio River has experienced more water recently compared to early records prior to the 1970s.

Hydrology - The Platte River is one of the largest tributaries to the Missouri River draining over 85,000 square miles of Colorado, Wyoming and Nebraska (USACE 2004b), and constitutes approximately 26% of the Missouri River drainage area upstream of its confluence. Many of the headwater tributaries, such as the North and South Platte Rivers, contain numerous dams and reservoirs designed for power generation, irrigation and water supply. Despite the alterations from pre-regulation periods, gage data from the Platte River watershed indicates increasing trends in annual and seasonal streamflow for the period 1960-2011 (Norton et al. 2014). Other significant tributaries within this reach include the Weeping Water Creek, Little Nemaha River and Big Nemaha River draining from the west and the Nishnabotna River draining from the east. Combined, the Platte Reach constitutes almost a quarter (22%) of the Missouri River drainage area above the Nodaway River. Flows from tributaries through this reach can significantly influence flow conditions along the Missouri River downstream, as reflected in the main stem gage data during the large Platte River flood events of 2010, 1984 and 1993. Most tributaries through this reach display increasing trends in streamflow data from 1960-2011 (Norton et al. 2014).

Most of the discharge data from Nebraska City, Nebraska primarily reflects streamflow responses strongly emulating climate (PDSI cycles) (Appendix B3). At times, however, stream responses following dry periods were slow despite several wet cycles. For example, the period 1952-1976 was primarily wet, but average annual discharge remained relatively low. Peak annual streamflow data at Nebraska City shows that peak floods were much higher prior to the 1950s, though dam effects at this point downstream are clearly dampened (Appendix B3d,e). Average daily flows over 150,000 cfs occurred much more frequently pre-regulation, every 2-5 years on average, compared to post-regulation frequencies of roughly 10 years, but peak streamflows reflect more similar magnitudes before and after regulation compared to records from upstream reaches (Appendix B3g). Pre-regulation floods were more common on a daily scale as well, with the current two-year flood levels occurring at least annually.

NODAWAY REACH

Climate - The growing season in this portion of the LMR averages 240 to 270 days (FAO 2007). Temperatures range from an average annual minimum of 44.1 degrees F to an average annual maximum of 64 degrees F, with a mean annual temperature of 54 degrees F (Appendix A). This area experiences roughly 89 days per year of measurable precipitation, and 35.9 inches of rain annually on average. Like upstream reaches, PDSI cycles in the Nodaway Reach exhibit 10-year wet and dry cycle alternations of wet/dry conditions, and severe drought occurs at about 20-year intervals, with total water year precipitation at Atchison, Kansas closely following these patterns (Appendix B4a-c).

HDCN gages on One Hundred and Two River and Nodaway River offer evidence of a long-term change in the regional hydrology as a result of climate change on top of other anthropogenic influences such as flow regulation or land use changes (Appendix B4d-g). Statistically significant increases in average ($p=0.007$) and minimum ($p<0.001$) temperatures in spring have been observed in this area (1950-2014). Similarly, mean ($p=0.043$) and minimum ($p<0.001$ temperatures) have increased in summer as well, based on data from the Atchison, USHCN station. In addition a weak negative correlation between SOI and average water year precipitation as a percent of normal at this station suggests the area may respond to El Nino events with higher than average precipitation.

Hydrology - The Nodaway River is a moderately sized tributary of the Missouri River, with a 1,935 square mile watershed that drains portions of western Iowa and northwest Missouri (Horton and Kerns

2002). The only other significant tributary to the Missouri River in this reach is the left-bank Platte River (the Missouri derived "Platte River", not to be confused with the larger Platte River that originates in Colorado and flows through Nebraska – see previous section), which has a 2,503 square mile basin in Iowa and Missouri (USACE 2004a). The mostly unregulated tributaries of this reach contribute a relatively small amount of drainage area and flow to the Missouri River. Flow dynamics through this reach are largely driven by Missouri River regulation and the larger tributaries in upstream reaches.

Average annual discharge peaks at Kansas City strongly mimic PDSI fluctuations (Appendix B4d-g). Discharges following the 1929 and 1945 wet cycles prior to streamflow regulations were much higher compared to those associated with the post-regulation wet period in 1960, which occurred after a drought of similar magnitude. The less-predictable nature of streamflow responses to climate after reservoir development suggest that upstream regulations at this point downstream have been dampened to some degree by tributary inputs.

Average annual discharge data from Kansas City indicate that post-regulation conditions are somewhat more comparable to pre-regulation conditions, and dam effects are much less obvious this far downstream. Though average and median flows are higher for the post-regulation period, the gap between the mean and median values is similar to those prior to regulation, suggesting a similar discharge frequency distribution for the two periods.

Peak annual discharges at Kansas City have a very similar range in magnitudes for the pre- and post-regulation periods. Farther upstream at the St. Joseph gage, differences in peak annual discharges are almost non-existent (Appendix B4h-k). However, floods at St. Joseph were still more common on a daily scale prior to regulations, and daily flows varied more. Seasonal pulses are also still clearly dampened by the dam system as well, and historically low-flows through fall and winter months are sustained at a much higher level.

KANSAS REACH

Climate - Immediately downstream of the confluence with the Kansas River, the Missouri River area has an annual average minimum and maximum temperatures ranging between 42.9-62.2 degrees F and an average temperature of 52.6 degrees F (Appendix A). The growing season lasts from 240-270 days, and measurable precipitation occurs roughly 98 days per year. Annual rainfall is 39.4 inches on average, based on data from 1950-2014.

Water year precipitation recorded at the Lees Summit Reed, Missouri USHCN station demonstrates patterns similar to the PDSI data, though extreme wet cycles are not always captured in the precipitation data (Appendix 5a,b). Transitions between wet and dry cycles occur every 10-15 years, and droughts have been relatively short in recent years (since the 1960s).

Hydroclimate trends are difficult to isolate from flow regulation impacts in this region, because no HCDN gages are located within the highly-altered Kansas River Basin, which is a major contributor to the flows in the portion of the LMR. HCDN gages in downstream reaches of the LMR (east of Kansas City) have not shown direct responses to climate changes; however these gages represent relatively small drainages compared to inputs from the Kansas River.

No significant climate changes have been observed in this area, based on seasonal averages from the Lees Summit Reed USHCN station. However, there is evidence of slight but insignificant increases in total water year precipitation (p=0.07) and average spring maximum temperatures (p=0.055) (1950-2014). In addition, a weak negative correlation between SOI and average water year precipitation as a percent of normal at this station also suggests the area may respond to El Nino events with higher than average precipitation.

Hydrology - The 60,580 square mile Kansas River watershed drains portions of Colorado, Nebraska and Kansas and is a major tributary to the Missouri River, comprising one-tenth of the entire Missouri River basin and increasing the drainage area of the Missouri River watershed at its confluence by 13 percent. The Kansas River basin is highly regulated with many demands placed on its waters (USACE 2004a). Data from Missouri River stream gages in the Kansas River watershed indicate downward trends in seasonal and annual streamflow for the period of 1960-2011 (Appendix B5c-f). Although inconclusive, these trends may be attributed, at least in part, to surface and ground water use within the watershed (Norton et al. 2014). Other significant tributaries through this reach include the Big and Little Blue Rivers. The Kansas River is a highly altered watershed with significant water supply deficiencies. Even so, the Kansas River contributes a sizeable portion of the Missouri River flow and has the ability to cause severe flooding, or influence the Missouri River's discharge during periods of low flow. Due to the influence of the Kansas River and its position within the watershed, flow dynamics with in this reach of the River can be highly influenced by the Kansas River and upstream tributaries, such as during the large Kansas River flood events in 2007, 1995, 1973 and 1993 and the subsequent response of the Missouri River downstream (Appendix B5c-e).

Average annual Missouri River discharge patterns in the Kansas Reach reflect changes in the climate data, and PDSI peaks correspond to 4-year moving average peaks in the average annual discharge data from Waverly, Missouri. Upstream dam effects are still evident in the form of higher average and median average annual flows for the post-regulation period, and this difference is primarily due to higher averages for low-flow years. Peak annual discharges are similar for the two periods, though pre-regulation data is relatively short. Daily flood frequencies, however, were higher prior to regulation, and average monthly discharges are clearly still impacted by regulation of the main stem and/or regulated tributary inputs upstream.

GRAND REACH

Climate - The Grand Reach of the Missouri River has a growing season range of 240-270 days (FAO 2007). Annual temperatures range from an average minimum of 43.6 degrees F to an average maximum of 63.2 degrees F, with a mean annual temp of 53.4 degrees F (Appendix A). Approximately 93 days per year of measurable precipitation are observed in this region, and average annual rainfall totals 38.6 inches.

PDSI data for this reach's climate divisions exhibit wet and dry cycles lasting 5-10 years on average (Appendix B6a,b) Extremely wet years occur every 20 years, with more frequent wet cycles in recent years (roughly every 10-15 years). Extreme droughts occur every 15 years on average. These patterns are also reflected by water year precipitation data from Brunswick, Missouri (Appendix B6c).

The following climate trends have been observed in this area, based on data from the Brunswick USHCN station (1950-2014):

- Average and minimum water year temperatures have increased significantly since the 1950s ($p=0.015$ and $p<0.001$, respectively).
- Average minimum temperatures during the cool season (October-March) have increased over time ($p=0.003$), and there is evidence of a slight increase in average cool season temperatures ($p=0.056$).
- Average mean ($p=0.014$) and minimum ($p<0.001$) spring temperatures have increased since the 1950s. There is also evidence of an increase in average minimum temperatures in summer ($p=0.05$).

- Negative trends in July NAO indices (1980-2010) with average summer precipitation suggest future climate scenarios of greater precipitation in this area.

Hydrology - The unregulated flows of the Grand River drain 7,883 square miles of southern Iowa and northern Missouri (USACE 1989, Pitchford and Kerns 1994). When coupled with the other tributaries, such as the Chariton and Little Chariton Rivers draining from the north and the Lamine River flowing from the south, this reach comprises approximately 13% of the Missouri River drainage area upstream of the Osage River (USACE 2004a). However, due to the size of the upstream watershed, the influence over Missouri River flow dynamics through this reach is primarily driven by upstream conditions and regulation.

Average annual discharges from Boonville, Missouri match drought/wet cycles of the PDSI data (Appendix B6d-g). High flow years match wet-cycle peaks of similar magnitudes between the pre- and post-regulation datasets, though low-flow years seem to vary more in response to climate. For example, low flows in response to drought through 1937 reflected similar average annual discharges to those through 1957, though the drought in the mid-1950s was more severe.

While upstream dam effects on Grand Reach hydrology are still evidenced by higher daily average discharge magnitudes, more-frequent flooding, more monthly variability, and higher fall/winter flows for the period prior to regulation; the average annual discharges are comparable between the two periods, as are peak annual streamflows. This is likely the result of inputs from relatively unaltered watersheds, such as the Grand River, which partially dampen the effects of upstream regulations.

OSAGE REACH

Climate – The mean annual precipitation at Washington, Missouri is about 41 inches with peaks in May and June, decreases until September when a small secondary peak occurs, and then gradually declines to stable levels in winter and early spring (Appendix A). About 102 days per year experience measurable precipitation (Menne et al. 2012), but daily rainfall was more common prior to the 1970s. Snow averages about 15 inches annually. Mean temperature in January is 35 degrees F and rises to peaks of 91 degrees in July. The growing season lasts between 210-270 days (FAO 2007), and is more spatially variable in this area compared to other reaches within the study area, due to slightly fewer frost-free days in areas surrounding the Osage and Gasconade rivers as they approach the Missouri River.

PDSI data shows similar patterns to climate divisions upstream, with wet and dry cycles lasting roughly 5-10 years, with extreme droughts occurring every 15-20 years (Appendix B7a,b). Recent wet cycles have been particularly wet compared to early records, while droughts have been of lower magnitudes. Compared to upstream reaches, patterns of the PDSI fluctuations were not as closely-demonstrated in the water year precipitation data from Warrenton, Missouri.

Based on data from the Warrenton station (1950-2014), average mean ($p=0.001$), minimum ($p=0.02$), and maximum ($p<0.001$) temperatures for the entire water year have increased significantly, though no precipitation trends were identified for on an annual or seasonal scale. Temperature increases have been most dramatic in the summer and spring. Average maximum, mean, and minimum temperatures for June-August have increased significantly ($p=0.027$, $p=0.014$, $p=0.016$ respectively). Average maximum ($p<0.001$) and mean ($p=0.002$) temperatures between March-May have risen from 1950s levels, as have average maximum and mean temperatures for the cool season between October and March ($p=0.005$ for average maximum temperatures, $p=0.011$ for average mean temperatures). Negative trends in July NAO indices (1980-2010) with average summer precipitation suggest future climate scenarios of greater precipitation in this area.

Hydrology - The Osage River drains about 15,088 square miles of eastern Kansas and central Missouri (Schubert 2001). The Osage and its tributaries have numerous impoundments that are managed for flood control and/or hydroelectric power production. The last significant downstream tributary to the Missouri River before it joins the Mississippi River is the Gasconade River, which drains southern and central Missouri about 104 miles upstream of the mouth (USACE 2004a). Flow dynamics through this reach strongly reflect upstream climatic conditions and regulation.

Average annual discharge from the Hermann, Missouri gage indicates a strong dependence on regional climatic conditions, with patterns closely following PDSI wet and dry cycles (Appendix B7c-f). Pre-regulation data from this gage reflect similar frequencies and magnitudes compared to average daily flows from post-regulation records in this reach. Peak streamflows are also relatively consistent throughout the entire period of record, as are average annual discharges. However, post-regulation records suggest the dataset has a more positive skew (i.e., high flow years are less common and/or low flow years are more common) compared to records from 1929-1951, when the data was more normally distributed. Effects of an altered hydrology from the main channel and tributary inputs also are still apparent this far downstream from dampened seasonal peak flows, and higher sustained flows through fall and winter. In particular, hydroelectric releases from a dam upstream on the Osage River impact water quantity on the main stem Missouri River (Schubert 2001).

Karen Kyle

APPENDIX A

Long-term temperature, precipitation, and growing season data (1971-2000) from: 1) Omaha, Nebraska; 2) St. Joseph, Missouri; 3) Kansas City, Missouri; 4) New Franklin, Missouri; and 5) Washington, Missouri (no temperature or growing season data). A total of 13 tables representing the six LMR reaches. (From www.ncdc.noaa.gov/oa/climate/normals/usnormals.html)

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Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 1309 ft. Lat: 41.367° N Lon: 96.017° W
Station: **OMAHA WSFO, NE US GHCND:USW00094918**

Temperature (°F)																						
Mean							Cooling Degree Days Base (above)						Heating Degree Days Base (below)				Mean Number of Days					
Month	Daily Max	Daily Min	Mean	Long Term Max Std. Dev.	Long Term Min Std. Dev.	Long Term Avg Std. Dev.	55	57	60	65	70	72	55	57	60	65	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
1	32.1	12.7	22.4	6.5	5.8	6.0	0	0	0	0	0	0	1010	1072	1165	1320	0.0	0.0	2.4	14.6	30.4	5.4
2	36.5	16.5	26.5	6.4	5.8	6.0	-7777	-7777	-7777	-7777	0	0	798	854	938	1078	0.0	0.0	4.7	10.1	26.4	3.4
3	49.2	26.6	37.9	5.3	3.9	4.3	10	6	3	1	-7777	-7777	540	598	688	841	0.0	0.0	14.9	3.5	21.7	0.6
4	62.3	37.6	50.0	4.9	3.0	3.8	63	47	29	11	3	1	215	259	330	462	0.0	0.2	24.8	0.1	8.3	0.0
5	71.8	50.0	60.9	3.6	3.3	3.2	218	174	116	48	14	8	35	53	88	175	0.0	0.1	30.7	0.0	0.5	0.0
6	80.7	59.6	70.2	2.7	2.4	2.4	455	397	311	180	81	52	1	2	7	26	-7777	2.6	30.0	0.0	0.0	0.0
7	84.8	65.0	74.9	2.9	2.1	2.4	617	555	462	311	173	126	0	-7777	-7777	4	0.4	6.9	31.0	0.0	0.0	0.0
8	82.8	62.7	72.7	3.5	3.0	3.0	550	489	397	252	129	90	-7777	1	2	12	0.1	5.0	31.0	0.0	0.0	0.0
9	75.5	52.9	64.2	3.4	2.4	2.7	297	248	181	94	35	21	21	32	55	118	0.0	1.4	29.6	0.0	0.2	0.0
10	63.3	41.0	52.1	4.0	2.5	2.9	78	55	31	9	2	1	166	206	275	408	0.0	0.0	27.6	0.1	5.7	0.0
11	47.8	27.9	37.8	6.1	4.8	5.3	9	6	3	-7777	0	0	524	580	667	815	0.0	0.0	13.5	3.4	19.3	0.3
12	33.8	15.7	24.7	6.4	6.3	6.2	-7777	-7777	-7777	0	0	0	938	1000	1093	1247	0.0	0.0	2.9	12.9	29.6	3.8
Summary	60.1	39.0	49.5	4.6	3.8	4.0	2297	1977	1533	906	437	299	4248	4657	5308	6506	0.5	16.2	243.1	44.7	142.1	13.5

@ Denotes mean number of days greater than 0 but less than 0.05.
-7777: a non-zero value that would round to zero
Empty or blank cells indicate data is missing or insufficient occurrences to compute value.

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National Oceanic & Atmospheric Administration
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Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 1309 ft. Lat: 41.367° N Lon: 96.017° W
Station: **OMAHA WSFO, NE US GHCND:USW00094918**

Precipitation (in.)								
	Totals	Mean Number of Days				Precipitation Probabilities Probability that precipitation will be equal to or less than the indicated amount		
	Means	Daily Precipitation				Monthly Precipitation vs. Probability Levels		
Month	Mean	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.25	.50	.75
1	0.70	4.7	2.1	0.3	0.0	0.33	0.56	1.07
2	0.86	5.8	2.5	0.3	-7777	0.41	0.76	1.12
3	2.12	8.3	4.8	1.7	0.4	0.98	1.69	3.22
4	3.44	9.7	6.2	2.1	0.7	2.02	3.09	4.25
5	4.70	12.7	8.3	3.1	1.4	3.43	4.10	6.08
6	4.12	10.0	6.6	2.7	1.3	2.52	3.49	4.94
7	3.95	9.6	6.4	2.9	1.1	2.59	3.12	4.87
8	3.53	8.3	5.4	1.7	0.8	1.46	2.63	6.05
9	2.86	8.2	5.6	1.9	0.5	1.74	2.81	3.69
10	2.42	7.4	4.6	1.7	0.5	1.44	1.93	3.23
11	1.49	6.2	3.4	1.0	0.4	0.72	1.08	2.06
12	1.02	6.7	2.8	0.5	0.1	0.50	0.73	1.20
Summary	31.21	97.6	58.7	19.9	7.2	18.14	25.99	41.78

Snow (in.)													
	Totals	Mean Number of Days									Snow Probabilities Probability that snow will be equal to or less than the indicated amount		
	Means	Snowfall >= Thresholds					Snow Depth >= Thresholds				Monthly Snow vs. Probability Levels Values derived from the incomplete gamma distribution.		
Month	Snowfall Mean	0.1	1.0	3.0	5.0	10.0	1	3	5	10	.25	.50	.75
1	5.2	3.3	1.6	0.5	-7777	0.0	13.3	10.3	5.8	0.4	2.2	4.2	7.1
2	4.5	3.5	1.3	0.3	0.1	0.0	12.0	8.0	4.7	0.5	1.4	3.5	7.0
3	5.1	2.7	1.3	0.7	0.2	0.0	5.1	3.3	2.2	0.6	0.5	5.0	6.6
4	1.6	1.0	0.4	0.1	-7777	0.0	1.2	0.5	0.2	0.0	0.0	0.0	1.5
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	-7777	-7777	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.9	0.5	0.3	0.1	-7777	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.8
11	3.9	2.5	1.3	0.3	-7777	0.0	3.1	1.0	0.6	0.0	0.4	2.8	5.8
12	5.3	4.0	1.6	0.5	0.1	0.0	10.7	5.7	2.6	0.8	3.5	4.9	7.0
Summary	26.5	17.5	7.8	2.5	0.4	0.0	45.8	28.9	16.1	2.3	8.0	20.4	35.8

@ Denotes mean number of days greater than 0 but less than 0.05.
-7777: a non-zero value that would round to zero
Empty or blank cells indicate data is missing or insufficient occurrences to compute value.

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Appendix A1 continued

1

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National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 1309 ft. Lat: 41.367° N Lon: 96.017° W
Station: **OMAHA WSFO, NE US GHCND:USW00094918**

Growing Degree Units (Monthly)												
Base	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	6	19	114	324	648	904	1081	1015	726	393	110	9
45	1	7	60	209	494	754	927	860	578	264	59	2
50	-7777	2	27	121	348	604	772	705	434	156	27	-7777
55	0	-7777	10	63	218	455	617	550	297	78	9	-7777
60	0	-7777	3	29	116	311	462	397	181	31	3	-7777
Growing Degree Units for Corn (Monthly)												
50/86	6	17	84	206	386	595	740	682	452	230	68	7

Growing Degree Units (Accumulated Monthly)												
Base	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	6	25	139	463	1111	2015	3096	4111	4837	5230	5340	5349
45	1	8	68	277	771	1525	2452	3312	3890	4154	4213	4215
50	0	2	29	150	498	1102	1874	2579	3013	3169	3196	3196
55	0	0	10	73	291	746	1363	1913	2210	2288	2297	2297
60	0	0	3	32	148	459	921	1318	1499	1530	1533	1533
Growing Degree Units for Corn (Monthly)												
50/86	6	23	107	313	699	1294	2034	2716	3168	3398	3466	3473

Note: For corn, temperatures below 50 are set to 50, and temperatures above 86 are set to 86
M indicates the value is missing
-7777: a non-zero value that would round to zero
Empty or blank cells indicate data is missing or insufficient occurrences to compute value.

Cary Aloia

2

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 818 ft. Lat: 39.774° N Lon: 94.923° W
Station: **ST JOSEPH ROSECRANS MEMORIAL AIRPORT, MO US GHCND:USW00013993**

Temperature (°F)																						
Mean							Cooling Degree Days Base (above)						Heating Degree Days Base (below)				Mean Number of Days					
Month	Daily Max	Daily Min	Mean	Long Term Max Std. Dev.	Long Term Min Std. Dev.	Long Term Avg Std. Dev.	55	57	60	65	70	72	55	57	60	65	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
1	37.1	17.4	27.2	6.1	6.0	5.8	-7777	-7777	-7777	0	0	0	860	922	1015	1170	0.0	0.0	5.8	10.8	28.6	2.8
2	42.3	21.6	32.0	6.5	5.4	5.7	1	1	-7777	0	0	0	647	702	786	925	0.0	0.0	8.3	6.1	23.1	1.1
3	54.5	31.4	42.9	4.6	3.6	3.8	23	16	8	2	-7777	0	397	451	537	685	0.0	0.0	19.7	0.9	17.4	0.1
4	65.8	42.5	54.2	4.3	3.2	3.7	105	80	52	19	5	2	131	166	227	345	0.0	0.1	27.1	0.0	4.8	0.0
5	75.4	53.3	64.4	3.2	3.0	2.8	302	250	182	92	35	21	12	23	47	112	0.0	1.5	31.0	0.0	0.1	0.0
6	84.0	63.3	73.6	2.7	2.4	2.4	559	500	410	267	140	98	-7777	-7777	1	8	0.0	5.2	30.0	0.0	0.0	0.0
7	87.0	67.1	77.1	2.8	2.4	2.3	683	621	528	374	227	172	0	0	0	1	0.4	10.3	31.0	0.0	0.0	0.0
8	86.3	64.3	75.3	3.7	3.8	3.6	629	567	474	323	185	139	-7777	-7777	-7777	4	0.7	9.5	31.0	0.0	0.0	0.0
9	79.1	54.0	66.6	3.1	3.1	2.9	356	302	226	122	50	32	9	15	30	75	0.1	2.5	29.9	0.0	0.1	0.0
10	67.0	42.5	54.7	3.5	2.6	2.5	115	88	56	21	8	5	123	158	218	339	0.0	0.2	29.1	0.0	4.7	0.0
11	52.9	31.0	41.9	5.1	3.8	4.2	16	10	4	1	-7777	0	407	461	546	692	0.0	0.0	17.4	1.2	16.9	0.0
12	39.2	19.7	29.4	6.5	6.0	6.0	1	1	-7777	0	0	0	793	854	947	1102	0.0	0.0	6.4	8.5	27.3	1.7
Summary	64.2	42.3	53.3	4.3	3.8	3.8	2790	2436	1940	1221	650	469	3379	3752	4354	5458	1.2	29.3	266.7	27.5	123.0	5.7

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U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 818 ft. Lat: 39.774° N Lon: 94.923° W
Station: **ST JOSEPH ROSECRANS MEMORIAL AIRPORT, MO US GHCND:USW00013993**

Precipitation (in.)								
	Totals	Mean Number of Days				Precipitation Probabilities Probability that precipitation will be equal to or less than the indicated amount		
	Means	Daily Precipitation				Monthly Precipitation vs. Probability Levels		
Month	Mean	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.25	.50	.75
1	0.56	4.4	1.8	0.4	0.0	0.14	0.50	0.78
2	0.93	5.6	2.2	0.6	0.1	0.39	0.83	1.24
3	2.25	8.1	4.7	1.0	0.4	1.24	2.04	3.41
4	3.79	9.9	6.5	2.5	1.2	2.23	3.77	4.59
5	5.42	12.8	7.0	3.0	1.2	3.76	5.34	6.63
6	4.18	12.2	7.2	3.5	1.5	2.96	4.02	4.96
7	5.19	11.1	4.8	2.3	1.1	1.89	4.43	7.18
8	3.98	12.1	6.0	3.0	1.6	2.50	3.22	5.46
9	3.42	11.0	5.1	2.3	0.9	2.22	2.76	3.76
10	2.81	9.4	5.7	1.7	0.8	1.98	2.75	3.85
11	1.55	5.7	2.5	0.7	0.3	0.94	1.41	2.24
12	1.52	6.1	2.4	0.7	0.1	0.51	1.29	2.23
Summary	35.60	108.4	55.9	21.7	9.2	20.76	32.36	46.33

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National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 818 ft. Lat: 39.774° N Lon: 94.923° W
Station: **ST JOSEPH ROSECRANS MEMORIAL AIRPORT, MO US GHCND:USW00013993**

Growing Degree Units (Monthly)												
Base	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	16	42	177	433	755	1009	1148	1094	796	462	155	24
45	4	17	98	303	600	859	993	939	647	323	86	9
50	1	6	50	190	447	709	838	784	498	205	40	3
55	-7777	1	23	105	302	559	683	629	356	115	16	1
60	-7777	-7777	8	52	182	410	528	474	226	56	4	-7777
Growing Degree Units for Corn (Monthly)												
50/86	18	35	124	265	468	687	792	739	514	290	102	18

Growing Degree Units (Accumulated Monthly)												
Base	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	16	58	235	668	1423	2432	3580	4674	5470	5932	6087	6111
45	4	21	119	422	1022	1881	2874	3813	4460	4783	4869	4878
50	1	7	57	247	694	1403	2241	3025	3523	3728	3768	3771
55	0	1	24	129	431	990	1673	2302	2658	2773	2789	2790
60	0	0	8	60	242	652	1180	1654	1880	1936	1940	1940
Growing Degree Units for Corn (Monthly)												
50/86	18	53	177	442	910	1597	2389	3128	3642	3932	4034	4052

Note: For corn, temperatures below 50 are set to 50, and temperatures above 86 are set to 86
M indicates the value is missing
-7777: a non-zero value that would round to zero
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U.S. Department of Commerce
National Oceanic & Atmospheric Administration
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Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 1005 ft. Lat: 39.297° N Lon: 94.731° W
Station: **KANSAS CITY INTERNATIONAL AIRPORT, MO US GHCND:USW00003947**

Temperature (°F)

Mean							Cooling Degree Days Base (above)						Heating Degree Days Base (below)				Mean Number of Days					
Month	Daily Max	Daily Min	Mean	Long Term Max Std. Dev.	Long Term Min Std. Dev.	Long Term Avg Std. Dev.	55	57	60	65	70	72	55	57	60	65	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
1	38.0	19.6	28.8	5.9	5.3	5.4	-7777	-7777	-7777	0	0	0	812	874	967	1122	0.0	0.0	6.0	9.6	26.8	2.0
2	43.3	23.8	33.5	5.6	5.2	5.2	3	2	1	-7777	0	0	603	658	741	881	0.0	0.0	9.4	5.9	21.1	1.1
3	55.1	33.4	44.2	4.2	3.5	3.6	33	23	12	3	-7777	-7777	366	418	501	646	0.0	0.0	19.6	1.1	14.0	0.1
4	65.7	44.0	54.8	4.3	3.3	3.7	119	93	61	25	6	3	123	157	215	329	0.0	0.2	27.1	0.0	3.1	0.0
5	74.8	54.2	64.5	3.3	3.2	3.1	307	254	183	88	31	18	13	22	43	104	0.0	0.5	31.0	0.0	0.0	0.0
6	83.5	63.6	73.5	2.8	2.4	2.5	557	497	408	266	141	100	-7777	1	2	9	0.2	4.7	30.0	0.0	0.0	0.0
7	88.3	68.4	78.3	2.8	2.1	2.3	724	662	569	414	264	207	0	0	0	-7777	0.8	12.4	31.0	0.0	0.0	0.0
8	87.4	66.8	77.1	4.1	2.9	3.4	685	623	530	377	233	182	0	-7777	-7777	2	1.7	11.7	31.0	0.0	0.0	0.0
9	79.0	57.3	68.2	3.3	2.9	2.9	404	349	271	159	77	53	9	14	26	65	0.1	3.1	29.9	0.0	0.1	0.0
10	66.9	45.9	56.4	2.9	2.5	2.4	139	107	68	26	7	4	96	125	179	293	0.0	0.1	29.2	0.0	1.9	0.0
11	53.2	34.1	43.6	5.2	4.1	4.4	25	17	8	2	-7777	-7777	365	417	499	642	0.0	0.0	17.9	1.3	12.4	0.0
12	40.3	22.6	31.5	6.0	5.9	5.8	1	1	-7777	0	0	0	731	792	885	1040	0.0	0.0	7.2	7.4	25.0	1.3
Summary	64.6	44.5	54.5	4.2	3.6	3.7	2997	2628	2111	1360	759	567	3118	3478	4058	5133	2.8	32.7	269.3	25.3	104.4	4.5

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Summary of Monthly Normals 1981-2010
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National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 1005 ft. Lat: 39.297° N Lon: 94.731° W
Station: **KANSAS CITY INTERNATIONAL AIRPORT, MO US GHCND:USW00003947**

Precipitation (in.)

	Totals	Mean Number of Days				Precipitation Probabilities Probability that precipitation will be equal to or less than the indicated amount		
	Means	Daily Precipitation				Monthly Precipitation vs. Probability Levels		
Month	Mean	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.25	.50	.75
1	1.07	6.3	2.6	0.5	0.1	0.58	0.97	1.40
2	1.46	7.1	3.5	0.9	0.2	0.73	1.34	2.11
3	2.37	9.5	5.3	1.7	0.3	1.34	2.29	2.94
4	3.70	11.0	6.8	2.6	0.8	2.13	3.56	4.93
5	5.23	11.5	7.8	3.7	1.5	2.84	4.79	6.97
6	5.23	10.8	7.5	3.8	1.7	3.36	4.81	6.87
7	4.45	9.0	5.9	2.6	1.3	1.72	4.33	6.02
8	3.89	8.3	5.5	2.4	1.1	1.87	3.58	5.04
9	4.62	8.6	6.3	3.2	1.4	2.22	3.43	7.63
10	3.16	8.2	5.5	2.0	0.8	1.39	3.13	3.85
11	2.15	7.3	4.2	1.3	0.5	1.24	2.01	2.84
12	1.53	7.2	3.2	0.9	0.3	0.75	1.33	2.08
Summary	38.86	104.8	64.1	25.6	10.0	20.17	35.57	52.68

Snow (in.)

	Totals	Mean Number of Days									Snow Probabilities Probability that snow will be equal to or less than the indicated amount		
	Means	Snowfall >= Thresholds					Snow Depth >= Thresholds				Monthly Snow vs. Probability Levels Values derived from the incomplete gamma distribution.		
Month	Snowfall Mean	0.1	1.0	3.0	5.0	10.0	1	3	5	10	.25	.50	.75
1	4.6	4.0	1.5	0.4	0.1	0.0	7.9	3.8	1.6	0.1	1.0	4.3	6.4
2	5.4	3.5	1.6	0.5	0.2	-7777	5.5	2.6	1.1	0.0	2.0	4.7	8.3
3	2.0	1.6	0.6	0.2	0.1	0.0	1.6	0.6	0.2	0.0	0.2	1.1	2.4
4	0.6	0.5	0.2	-7777	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.2	0.1	0.1	-7777	-7777	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	1.2	1.2	0.4	0.1	-7777	0.0	0.6	0.1	-7777	0.0	0.0	0.5	1.2
12	4.8	3.7	1.5	0.5	0.1	0.0	5.9	2.7	1.5	-7777	0.7	3.4	7.1
Summary	18.8	14.6	5.9	1.7	0.5	0.0	21.6	9.8	4.4	0.1	3.9	14.0	25.4

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Continued next page

Appendix A3 continued

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U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 1005 ft. Lat: 39.297° N Lon: 94.731° W
Station: **KANSAS CITY INTERNATIONAL AIRPORT, MO US GHCND:USW00003947**

Growing Degree Units (Monthly)												
Base	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	26	58	212	452	759	1007	1189	1150	845	512	192	39
45	9	25	127	320	605	856	1034	995	695	368	114	15
50	2	9	68	206	451	706	879	840	547	241	57	5
55	-7777	3	33	119	307	557	724	685	404	139	25	1
60	-7777	1	12	61	183	408	569	530	271	68	8	-7777
Growing Degree Units for Corn (Monthly)												
50/86	20	40	135	267	469	686	820	781	546	298	108	24

Growing Degree Units (Accumulated Monthly)												
Base	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	26	84	296	748	1507	2514	3703	4853	5698	6210	6402	6441
45	9	34	161	481	1086	1942	2976	3971	4666	5034	5148	5163
50	2	11	79	285	736	1442	2321	3161	3708	3949	4006	4011
55	0	3	36	155	462	1019	1743	2428	2832	2971	2996	2997
60	0	1	13	74	257	665	1234	1764	2035	2103	2111	2111
Growing Degree Units for Corn (Monthly)												
50/86	20	60	195	462	931	1617	2437	3218	3764	4062	4170	4194

Note: For corn, temperatures below 50 are set to 50, and temperatures above 86 are set to 86
M indicates the value is missing
-7777: a non-zero value that would round to zero
Empty or blank cells indicate data is missing or insufficient occurrences to compute value.

Karen Kyle

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U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Elev: 641 ft. Lat: 39.017° N Lon: 92.756° W
Station: **NEW FRANKLIN 1 W, MO US GHCND:USC00236012**

Summary of Monthly Normals 1981-2010

Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Temperature (°F)

	Mean						Cooling Degree Days Base (above)						Heating Degree Days Base (below)				Mean Number of Days					
Month	Daily Max	Daily Min	Mean	Long Term Max Std. Dev.	Long Term Min Std. Dev.	Long Term Avg Std. Dev.	55	57	60	65	70	72	55	57	60	65	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
1	37.9	17.8	27.8	5.3	5.0	5.0	1	-7777	-7777	0	0	0	842	904	997	1151	0.0	0.0	5.4	9.6	28.5	2.5
2	42.9	21.8	32.3	5.5	5.6	5.4	2	1	-7777	-7777	0	0	636	691	774	914	0.0	0.0	8.8	5.7	23.2	1.4
3	54.2	32.2	43.2	4.1	3.1	3.5	27	19	10	2	-7777	-7777	393	446	531	678	0.0	0.0	19.0	1.4	16.3	0.0
4	64.9	42.4	53.6	4.3	3.3	3.6	104	80	50	18	3	1	145	181	241	359	0.0	0.1	26.6	-7777	4.0	0.0
5	74.3	53.2	63.7	3.4	3.5	3.3	289	238	168	79	25	14	18	28	52	118	0.0	0.4	30.9	0.0	-7777	0.0
6	82.9	62.5	72.7	2.7	2.2	2.3	531	472	384	243	123	84	-7777	1	3	12	0.1	3.0	30.0	0.0	0.0	0.0
7	87.6	66.6	77.1	2.4	2.0	1.8	685	623	530	376	228	174	0	0	-7777	1	0.5	11.1	31.0	0.0	0.0	0.0
8	86.7	64.7	75.7	3.8	2.9	3.2	642	580	487	335	196	148	-7777	-7777	-7777	3	0.8	10.1	31.0	0.0	0.0	0.0
9	78.7	55.0	66.9	2.9	2.7	2.6	368	314	239	132	57	37	12	19	33	76	-7777	2.4	30.0	0.0	0.1	0.0
10	67.4	43.3	55.4	3.0	2.7	2.5	120	91	56	18	4	2	109	142	200	317	0.0	0.1	29.3	0.0	3.7	0.0
11	54.1	33.4	43.7	4.9	3.8	4.0	25	16	8	1	-7777	-7777	363	414	495	639	0.0	0.0	18.1	1.0	13.9	0.1
12	40.7	21.6	31.2	5.4	5.7	5.4	2	1	-7777	0	0	0	741	802	894	1049	0.0	0.0	7.2	7.0	26.4	1.6
Summary	64.4	42.9	53.6	4.0	3.5	3.6	2796	2435	1932	1204	636	460	3259	3628	4220	5317	1.4	27.2	267.3	24.7	116.1	5.6

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U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Elev: 641 ft. Lat: 39.017° N Lon: 92.756° W
Station: **NEW FRANKLIN 1 W, MO US GHCND:USC00236012**

Summary of Monthly Normals 1981-2010

Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Precipitation (in.)

	Totals	Mean Number of Days				Precipitation Probabilities Probability that precipitation will be equal to or less than the indicated amount		
	Means	Daily Precipitation				Monthly Precipitation vs. Probability Levels		
Month	Mean	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.25	.50	.75
1	1.76	6.8	3.7	0.9	0.5	0.83	1.64	2.42
2	2.05	6.5	4.1	1.4	0.4	1.10	1.86	2.51
3	2.80	8.6	5.6	1.9	0.5	1.57	2.68	3.88
4	3.98	10.2	6.7	2.8	1.0	2.16	3.56	6.12
5	5.13	12.1	8.2	3.6	1.5	2.69	4.69	6.82
6	5.03	10.4	7.2	3.3	1.5	2.98	4.02	7.36
7	4.21	8.7	6.2	2.9	1.3	2.13	3.84	6.26
8	4.40	8.4	5.7	2.8	1.5	2.41	3.65	5.74
9	3.99	8.2	5.9	2.5	1.1	2.04	2.81	4.69
10	3.39	9.1	6.2	2.4	0.8	1.81	2.95	4.36
11	3.00	8.1	5.2	2.2	0.6	1.67	2.31	4.01
12	2.25	7.1	4.4	1.5	0.5	1.05	2.15	2.83
Summary	41.99	104.2	69.1	28.2	11.2	22.44	36.16	57.00

Snow (in.)

	Totals	Mean Number of Days									Snow Probabilities Probability that snow will be equal to or less than the indicated amount		
	Means	Snowfall >= Thresholds					Snow Depth >= Thresholds				Monthly Snow vs. Probability Levels Values derived from the incomplete gamma distribution.		
Month	Snowfall Mean	0.1	1.0	3.0	5.0	10.0	1	3	5	10	.25	.50	.75
1	2.6	1.3	1.0	0.3	0.1	0.0	4.4	1.4	0.8	-7777	0.0	2.0	4.3
2	4.1	1.6	1.3	0.3	0.1	0.0	3.7	1.5	0.4	0.0	0.2	3.8	5.7
3	1.0	0.3	0.3	0.1	0.1	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	-7777	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.3	0.2	0.2	-7777	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0
12	4.1	1.2	1.0	0.3	0.1	0.1	3.9	1.7	0.4	0.2	0.0	2.0	6.0
Summary	12.1	4.6	3.8	1.0	0.4	0.1	12.7	4.8	1.6	0.2	0.2	7.8	16.0

@ Denotes mean number of days greater than 0 but less than 0.05.
-7777: a non-zero value that would round to zero
Empty or blank cells indicate data is missing or insufficient occurrences to compute value.

Continued next page

Appendix A4 continued

4

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 641 ft. Lat: 39.017° N Lon: 92.756° W
Station: **NEW FRANKLIN 1 W, MO US GHCND:USC00236012**

Growing Degree Units (Monthly)												
Base	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	21	48	188	419	736	981	1150	1106	805	480	192	36
45	7	20	110	292	582	831	995	951	656	338	114	14
50	2	7	58	184	430	681	840	797	509	215	58	5
55	1	2	27	104	289	531	685	642	368	120	25	2
60	-7777	-7777	10	50	168	384	530	487	239	56	8	-7777
Growing Degree Units for Corn (Monthly)												
50/86	19	38	124	251	454	665	789	748	519	294	116	26

Growing Degree Units (Accumulated Monthly)												
Base	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	21	69	257	676	1412	2393	3543	4649	5454	5934	6126	6162
45	7	27	137	429	1011	1842	2837	3788	4444	4782	4896	4910
50	2	9	67	251	681	1362	2202	2999	3508	3723	3781	3786
55	1	3	30	134	423	954	1639	2281	2649	2769	2794	2796
60	0	0	10	60	228	612	1142	1629	1868	1924	1932	1932
Growing Degree Units for Corn (Monthly)												
50/86	19	57	181	432	886	1551	2340	3088	3607	3901	4017	4043

Note: For corn, temperatures below 50 are set to 50, and temperatures above 86 are set to 86
M indicates the value is missing
-7777: a non-zero value that would round to zero
Empty or blank cells indicate data is missing or insufficient occurrences to compute value.

Karen Kyle

5

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Summary of Monthly Normals 1981-2010
Generated on 06/04/2015

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 487 ft. Lat: 38.542° N Lon: 90.975° W
Station: **WASHINGTON, MO US GHCND:USC00238746**

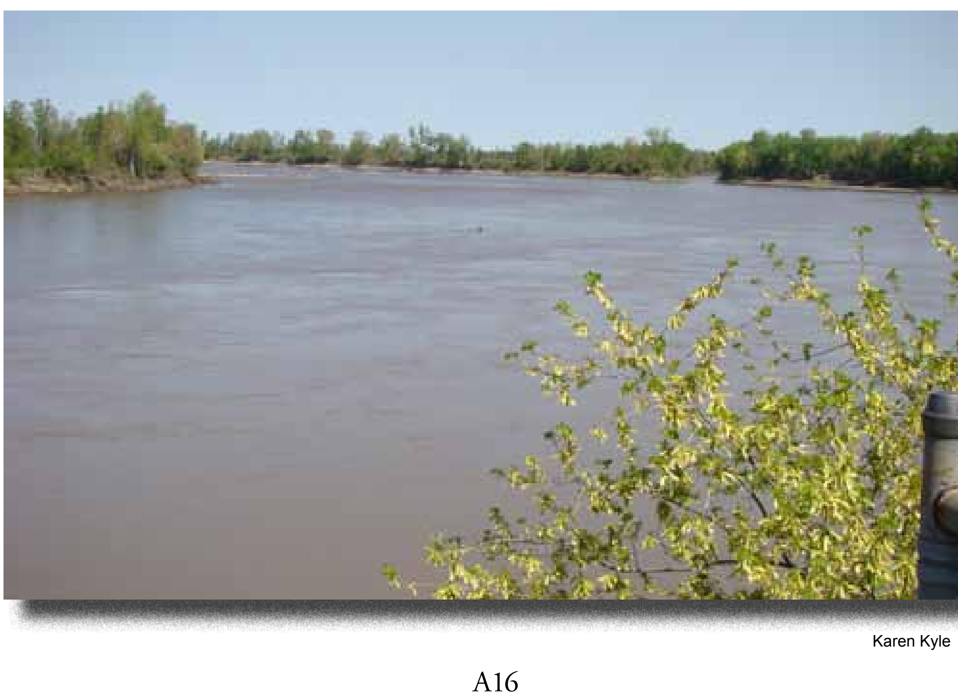
Precipitation (in.)

	Totals	Mean Number of Days				Precipitation Probabilities Probability that precipitation will be equal to or less than the indicated amount		
	Means	Daily Precipitation				Monthly Precipitation vs. Probability Levels		
Month	Mean	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.25	.50	.75
1	2.45	8.3	4.6	1.7	0.9	1.20	2.11	3.11
2	2.36	7.8	4.4	1.5	0.6	1.46	2.14	3.78
3	3.41	10.1	6.6	2.4	0.6	2.34	3.36	4.26
4	3.65	11.1	7.2	3.0	1.0	2.33	3.22	4.41
5	4.95	12.9	8.2	3.3	1.5	2.83	4.32	5.63
6	4.09	10.3	6.9	3.1	1.1	3.24	3.89	4.67
7	4.12	8.5	5.6	2.8	1.1	2.29	3.90	4.91
8	3.28	7.6	5.5	2.4	0.8	1.99	3.01	4.30
9	3.93	7.5	5.0	2.5	1.1	2.05	3.23	5.27
10	3.90	8.8	5.6	2.6	1.2	2.46	3.07	5.22
11	4.22	8.4	5.8	2.8	0.9	1.89	3.87	5.94
12	3.11	8.2	4.6	1.3	0.6	1.85	3.12	3.52
Summary	43.47	109.5	70.0	29.4	11.4	25.93	39.24	55.02

Snow (in.)

	Totals	Mean Number of Days									Snow Probabilities Probability that snow will be equal to or less than the indicated amount		
	Means	Snowfall >= Thresholds					Snow Depth >= Thresholds				Monthly Snow vs. Probability Levels Values derived from the incomplete gamma distribution.		
Month	Snowfall Mean	0.1	1.0	3.0	5.0	10.0	1	3	5	10	.25	.50	.75
1	2.9	1.7	1.2	0.3	0.1	0.0	@	@	@	@	0.3	2.7	4.6
2	1.4	1.4	0.6	0.2	0.0	0.0	@	@	@	@	0.0	0.0	2.5
3	0.7	0.4	0.2	0.1	0.1	0.0	@	@	@	@	0.0	0.0	0.1
4	0.1	0.1	0.1	0.0	0.0	0.0	@	@	@	@	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	@	@	@	@	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	@	@	@	@	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	@	@	@	@	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	@	@	@	@	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	@	@	@	@	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	@	@	@	@	0.0	0.0	0.0
11	0.3	0.2	0.2	0.0	0.0	0.0	@	@	@	@	0.0	0.0	0.0
12	2.9	1.6	0.9	0.4	0.2	0.0	@	@	@	@	0.0	2.1	5.4
Summary	8.3	5.4	3.2	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.3	4.8	12.6

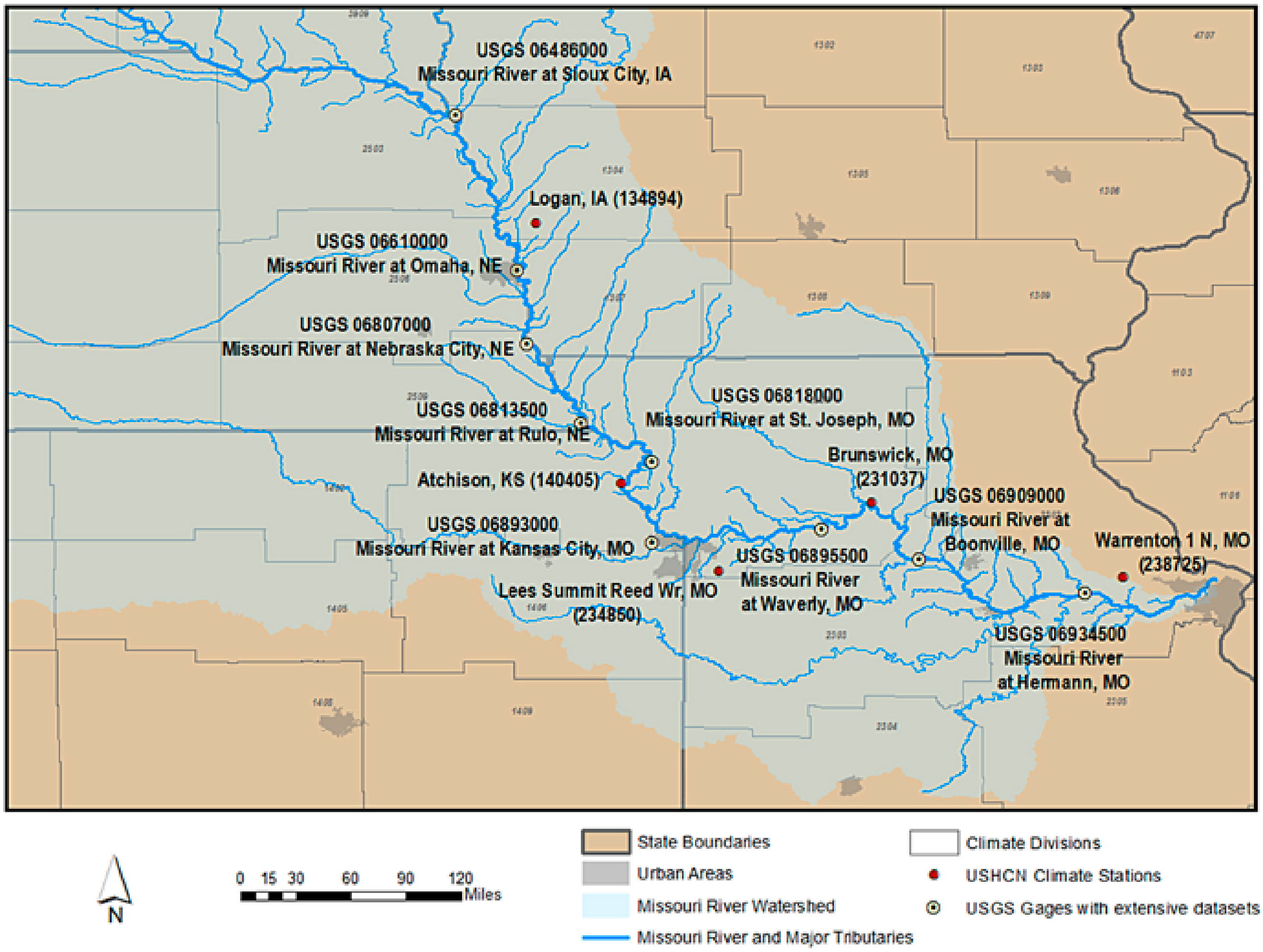
@ Denotes mean number of days greater than 0 but less than 0.05.
-7777: a non-zero value that would round to zero
Empty or blank cells indicate data is missing or insufficient occurrences to compute value.



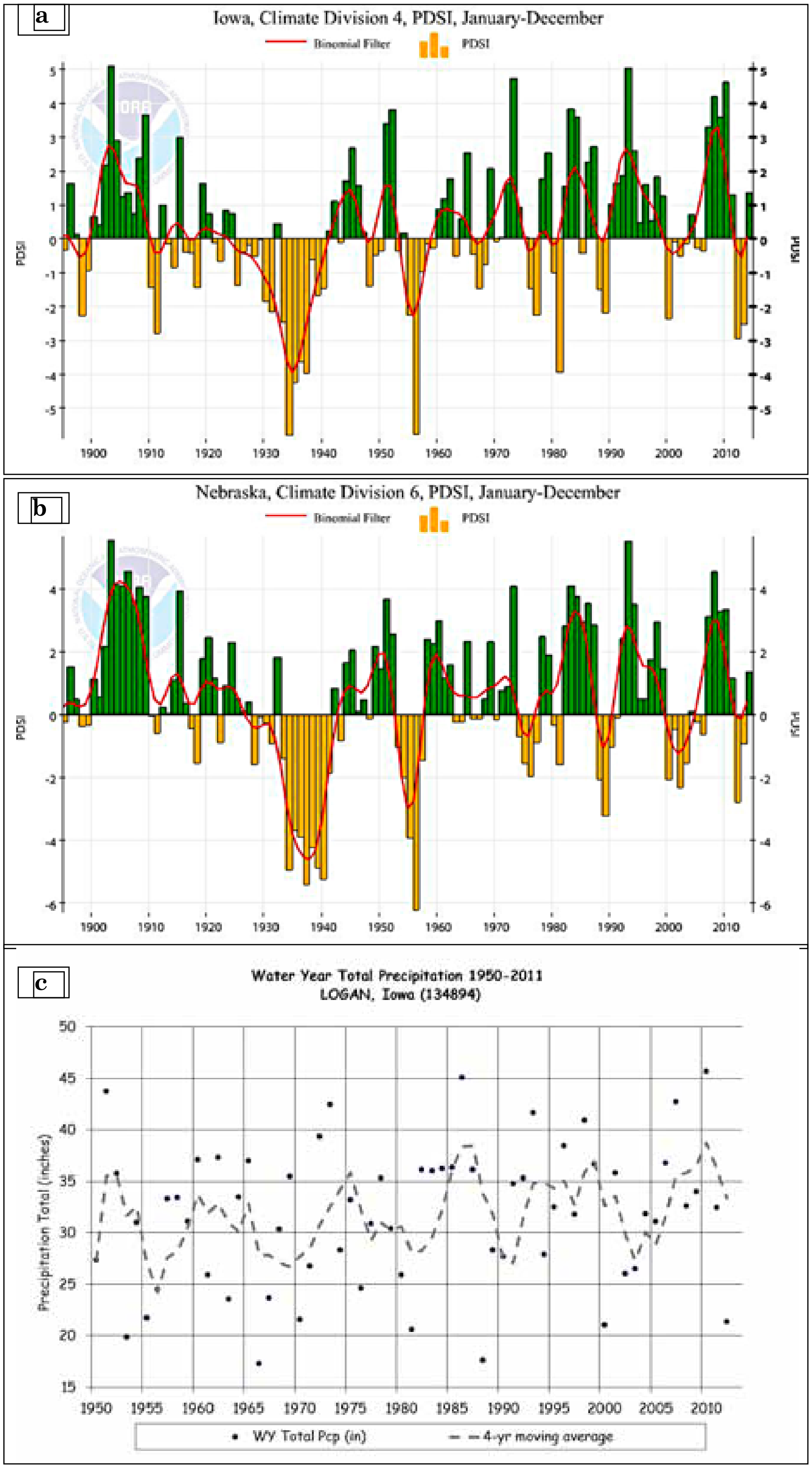
Karen Kyle

APPENDIX B

B1. USHCN climate and USGS river gage stations in the LMR.



B2. Palmer drought severity index trends relevant to the Little Sioux Reach for: a) Iowa Climate Division 4; and b) Nebraska Climate Division 6; c) total precipitation trends near Logan, Iowa 1950-2011 (USHCN station no. 134894); and Missouri River gage data from Omaha, Nebraska (USGS 06610000) for d) annual peak streamflow; e) average monthly discharges; f) average annual discharges; and g) average daily streamflow pre- (1928-1953) and post- (1954-2015) regulation periods.



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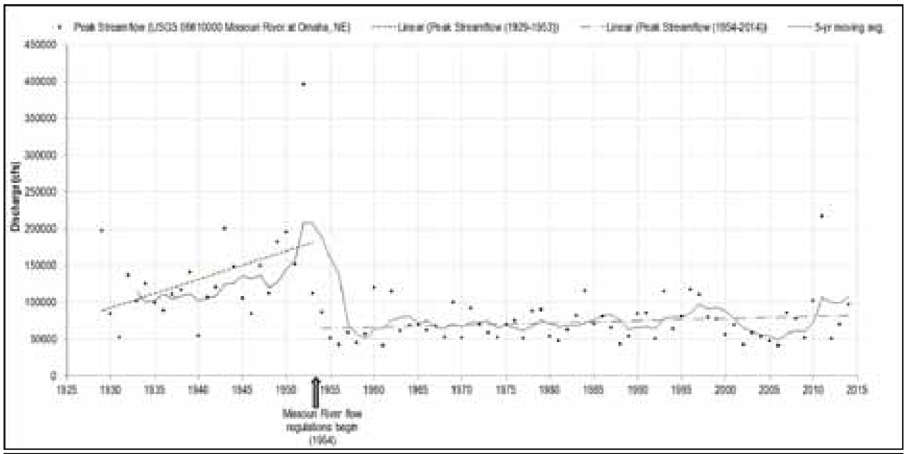
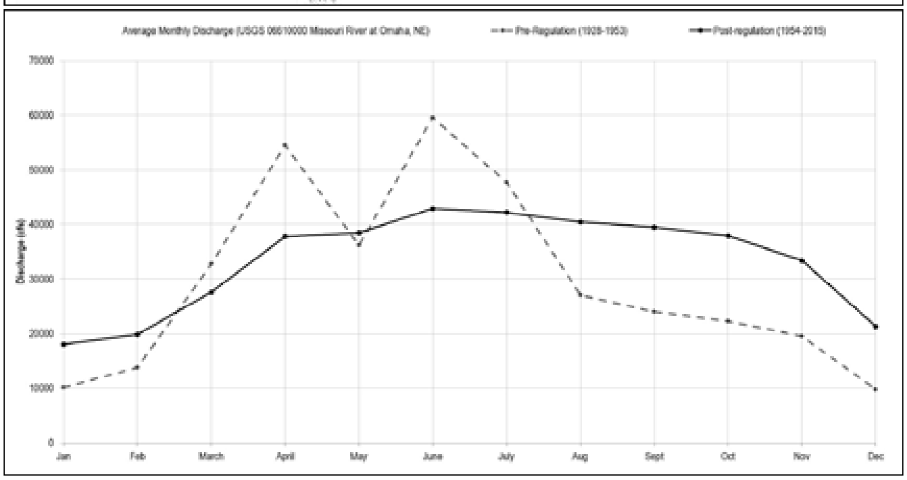
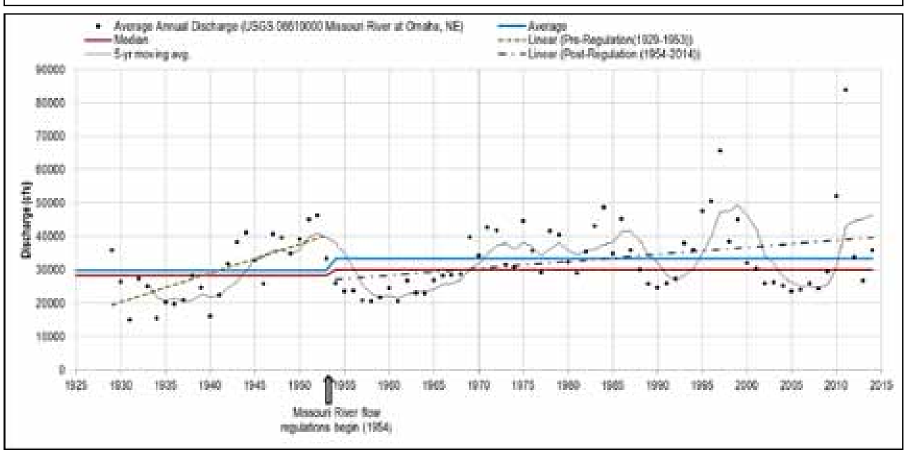

Peak Streamflow (USGS 06610000 Missouri River at Omaha, NE)
Linear (Peak Streamflow (1929-1953))
Linear (Peak Streamflow (1954-2014))
5-yr moving avg.
Discharge (cfs)
Missouri River flow regulations begin (1954)

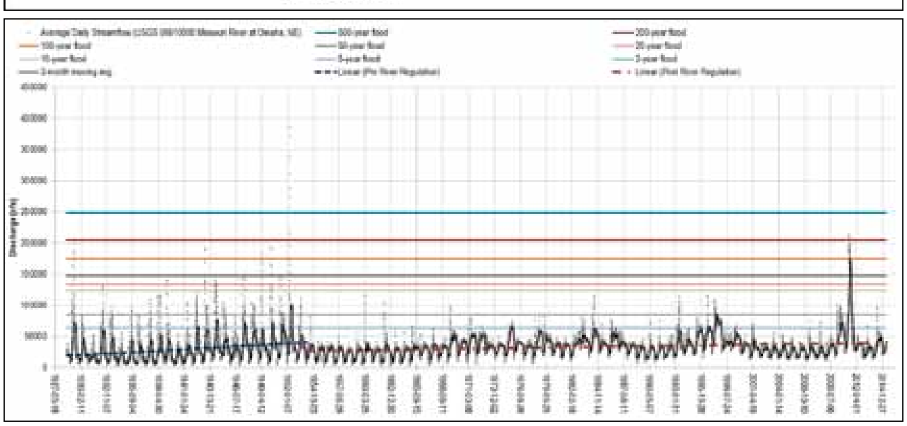
e


Average Monthly Discharge (USGS 06610000 Missouri River at Omaha, NE)
Pre-Regulation (1928-1953)
Post-regulation (1954-2015)
Discharge (cfs)
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec

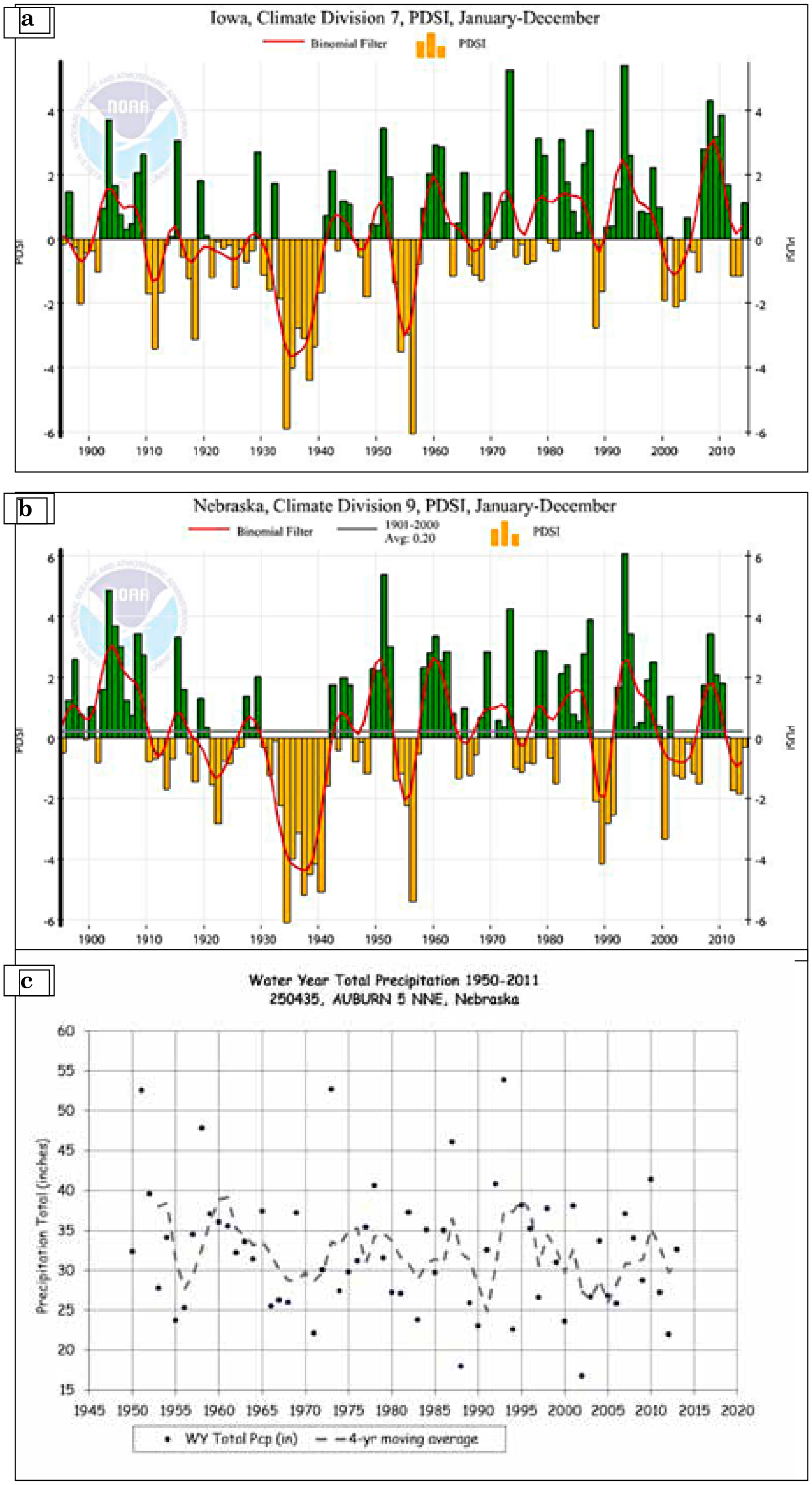
f


Average Annual Discharge (USGS 06610000 Missouri River at Omaha, NE)
Average
Median
Linear (Pre-Regulation(1929-1953))
5-yr moving avg.
Linear (Post-Regulation (1954-2014))
Discharge (cfs)
Missouri River flow regulations begin (1954)

g



B3. Palmer drought severity index trends relevant to the Platte Reach for: a) Iowa Climate Division 7; and b) Nebraska Climate Division 9; c) total precipitation trends near Auburn, Nebraska 1950-2011 (USHCN station no. 250435); and Missouri River gage data from Nebraska City, Nebraska (USGS 06807000) for d) annual peak streamflow; e) average monthly discharges; f) average annual discharges; and g) average daily streamflow pre- (1930-1953) and post- (1954-2015) regulation periods.



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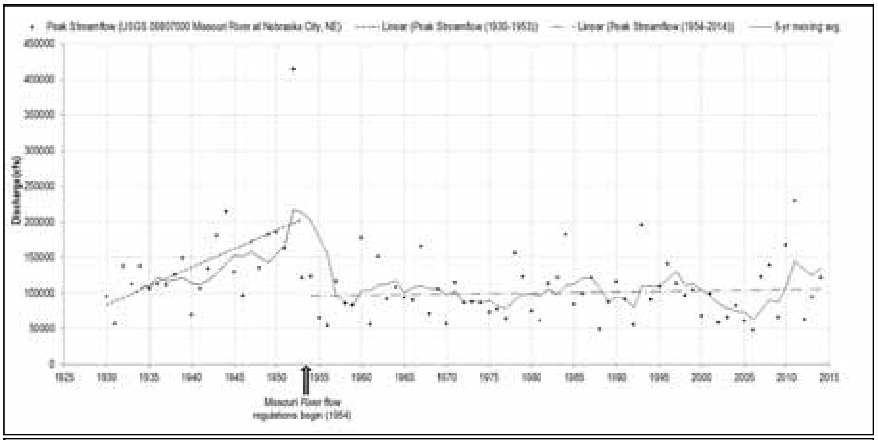
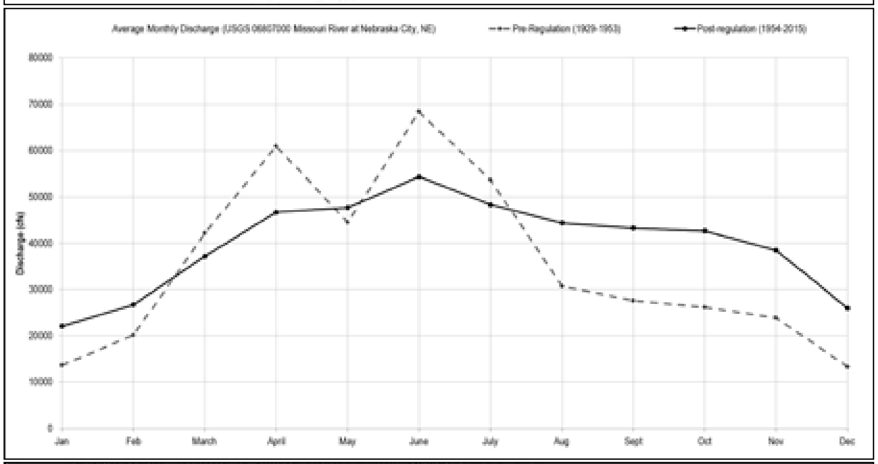
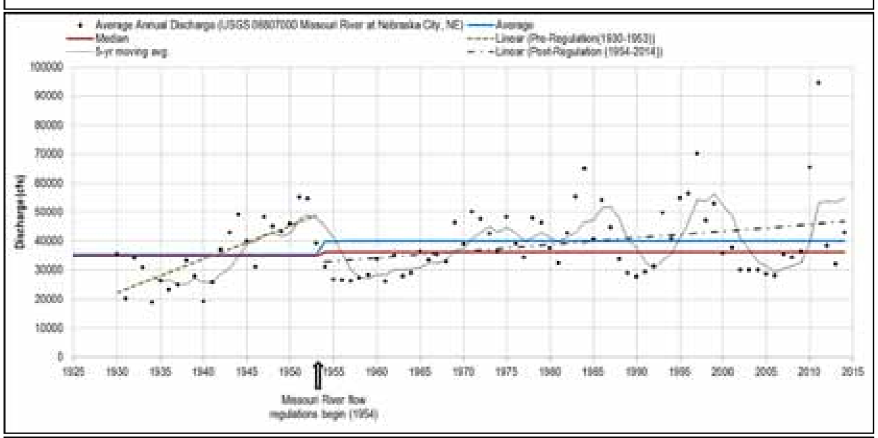

Peak Streamflow (USGS 06807000 Missouri River at Nebraska City, NE)
Linear (Peak Streamflow (1930-1953))
Linear (Peak Streamflow (1954-2014))
5-yr moving avg.
Discharge (cfs)
Missouri River flow regulations begin (1954)

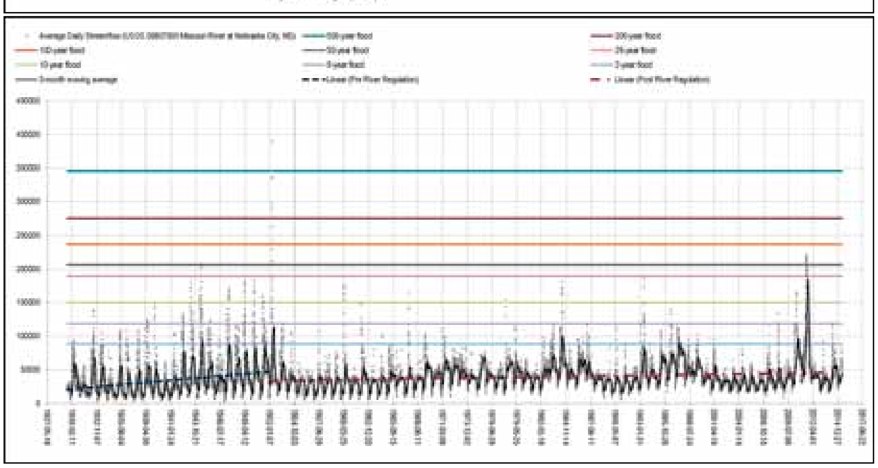
e


Average Monthly Discharge (USGS 06807000 Missouri River at Nebraska City, NE)
Pre-Regulation (1929-1953)
Post-regulation (1954-2015)
Discharge (cfs)
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec

f

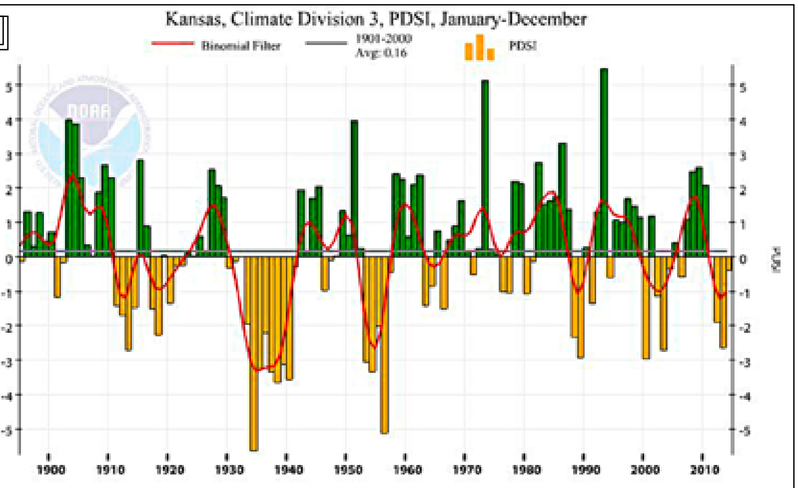

Average Annual Discharge (USGS 06807000 Missouri River at Nebraska City, NE)
Average
Median
Linear (Pre-Regulation(1930-1953))
5-yr moving avg.
Linear (Post-Regulation (1954-2014))
Discharge (cfs)
Missouri River flow regulations begin (1954)

g

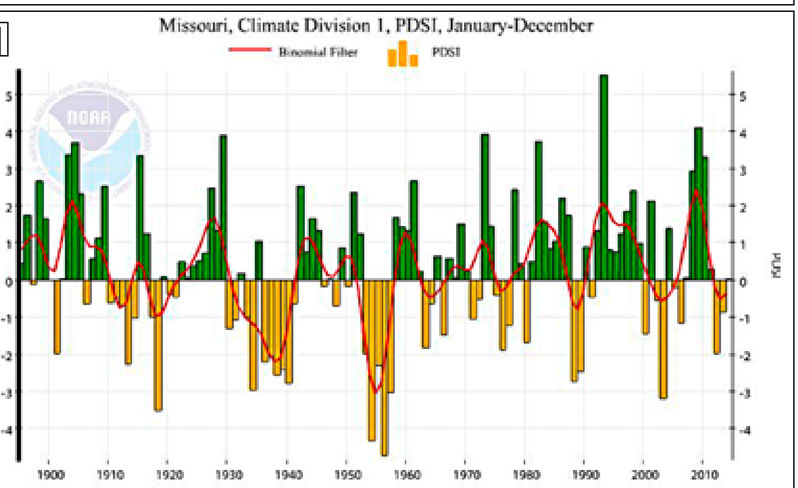


B4. Palmer drought severity index trends relevant to the Nodaway Reach for: a) Kansas Climate Division 3; and b) Missouri Climate Division 1; c) total precipitation trends near Atchison, Kansas 1950-2014 (USHCN station no. 140405); Missouri River gage data from Kansas City, Missouri (USGS 06893000) for d) annual peak streamflow; e) average monthly discharges; f) average annual discharges; and g) average daily streamflow pre- (1929-1953) and post- (1954-2015) regulation periods; and Missouri river gage data from St. Joseph, Missouri (USGS 06818000) for h) annual peak streamflow; i) average monthly discharges; j) average annual discharges; and k) average daily streamflow pre- (1929-1953) and post- (1954-2015) regulation periods.

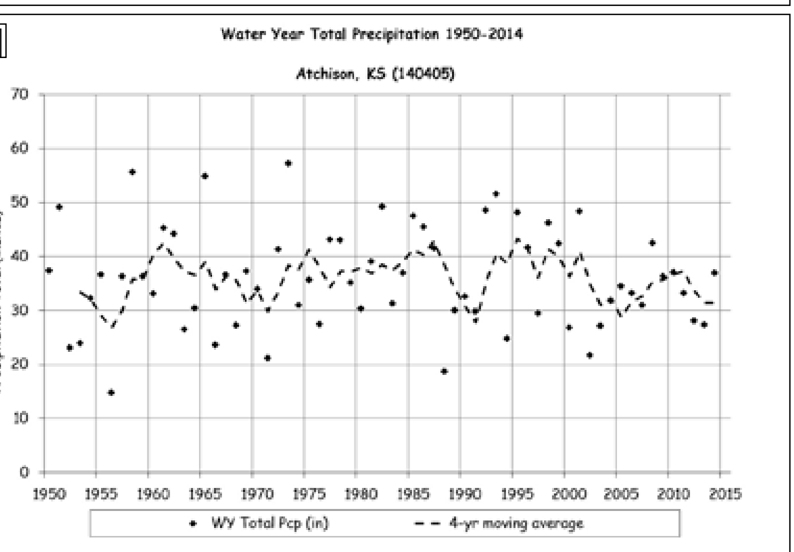
a



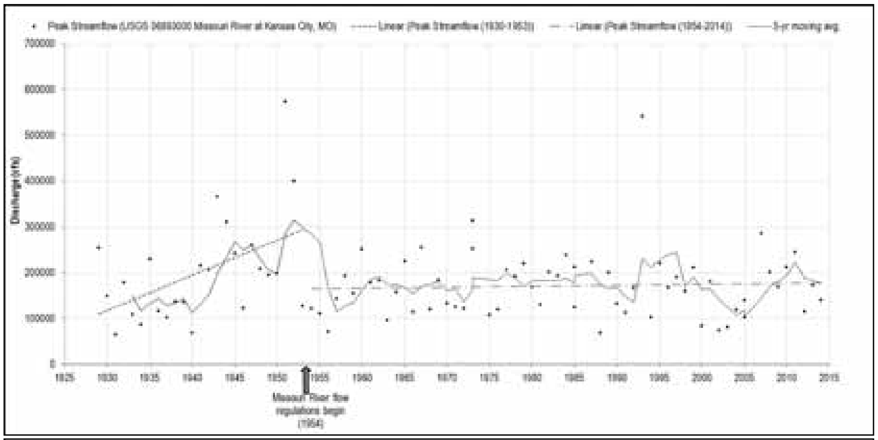
b



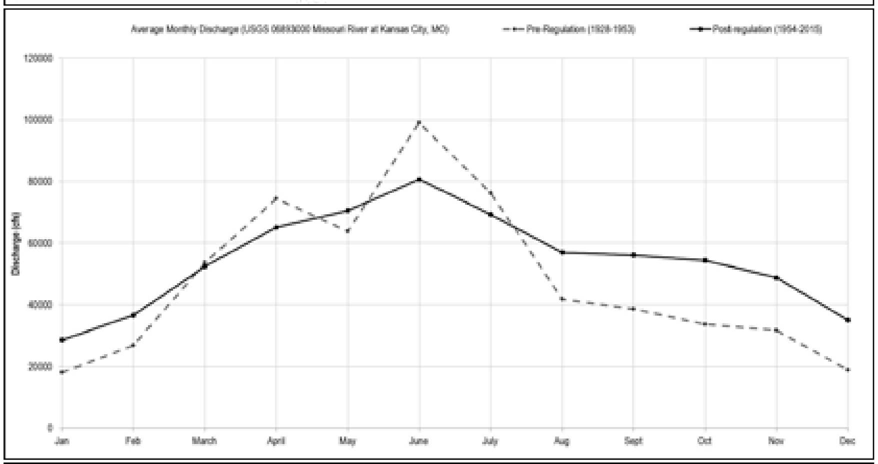
c



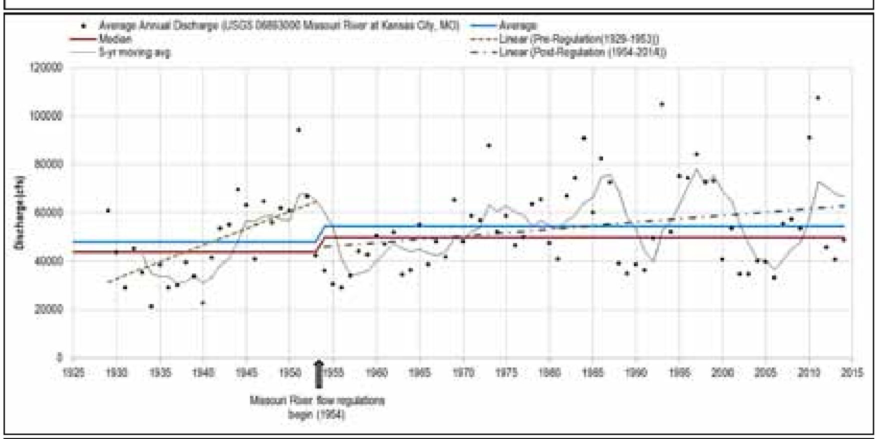
d



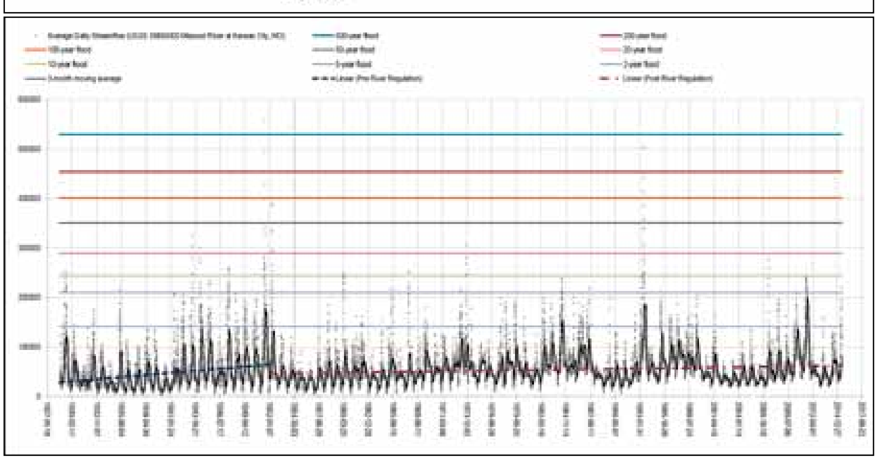
e



f



g



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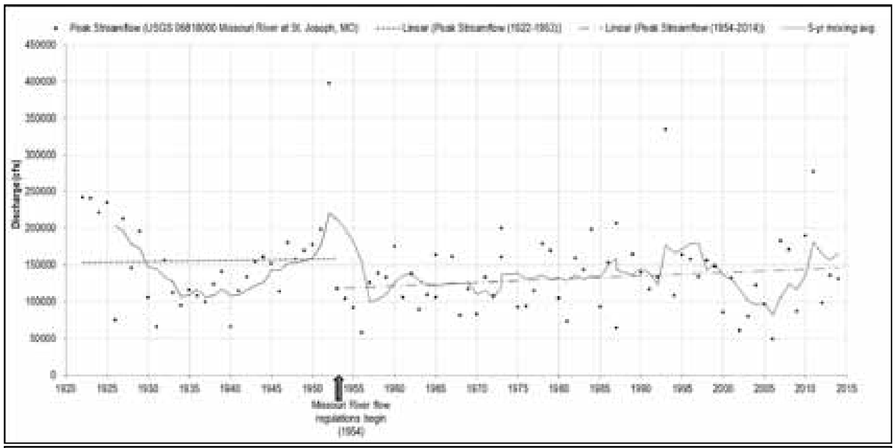
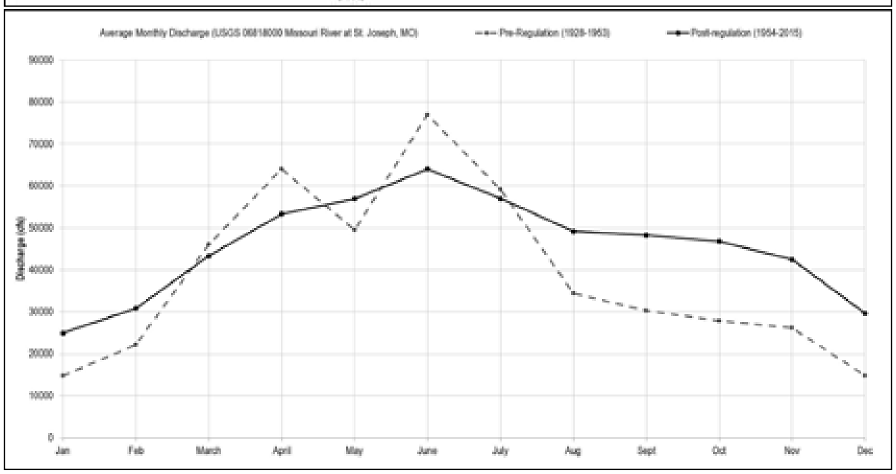
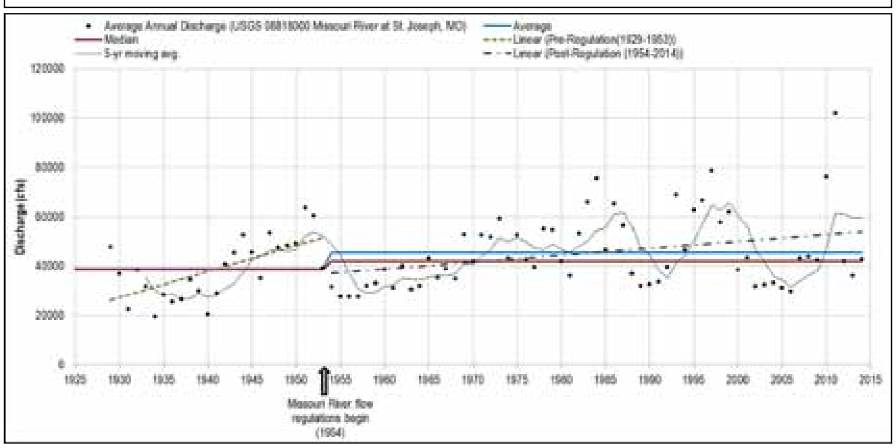
h


Peak Streamflow (USGS 06818000 Missouri River at St. Joseph, MO)
Linear (Peak Streamflow (1922-1953))
Linear (Peak Streamflow (1954-2014))
5-yr moving avg.
Discharge (cfs)
0
50000
100000
150000
200000
250000
300000
350000
400000
450000
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Missouri River flow regulations begin (1954)

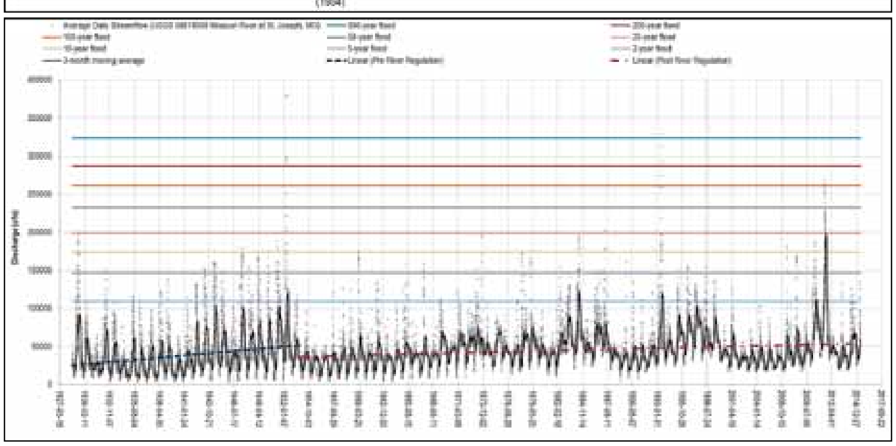
i


Average Monthly Discharge (USGS 06818000 Missouri River at St. Joseph, MO)
Pre-Regulation (1928-1953)
Post-regulation (1954-2015)
Discharge (cfs)
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec

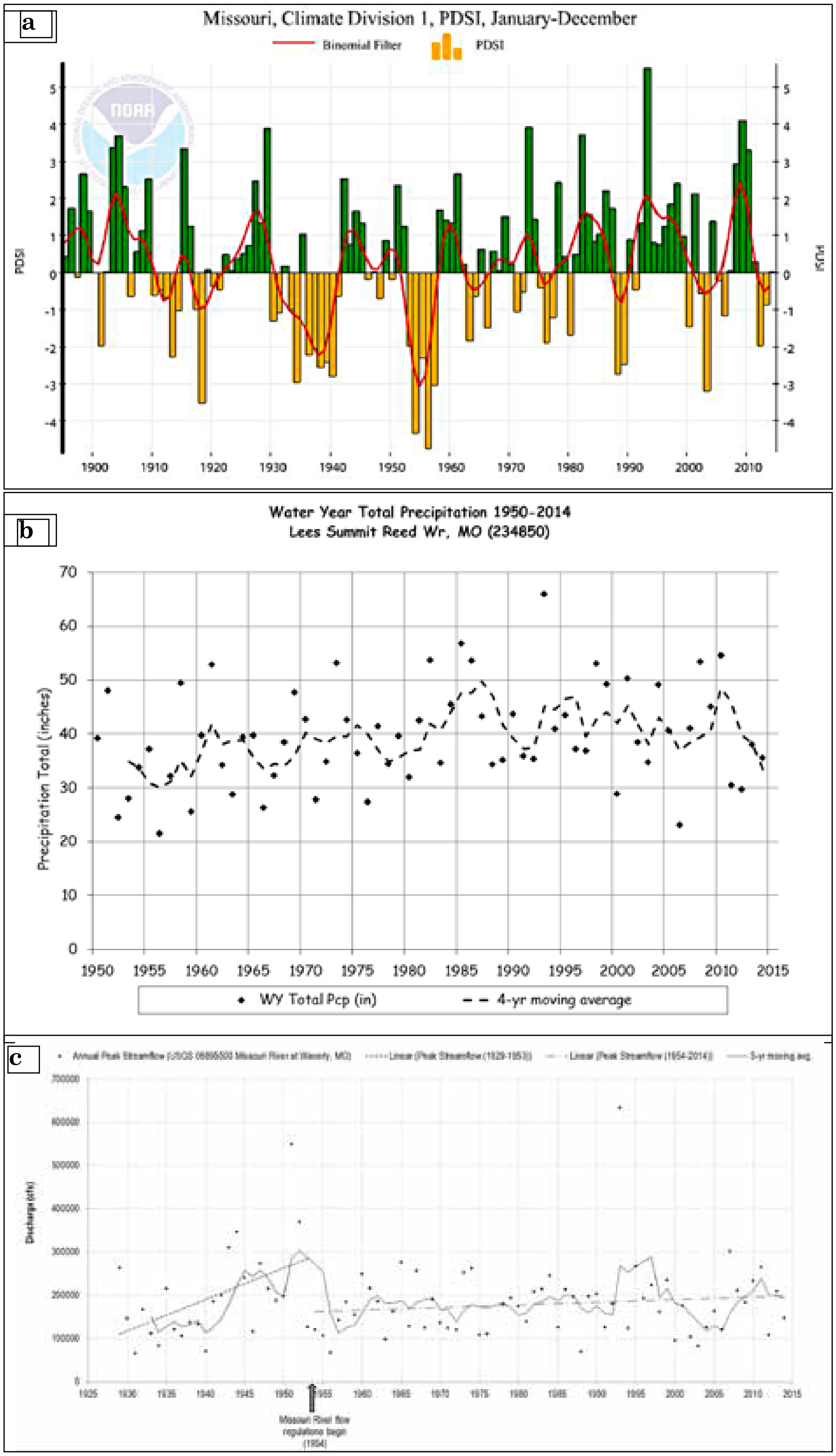
j


Average Annual Discharge (USGS 06818000 Missouri River at St. Joseph, MO)
Median
5-yr moving avg.
Average
Linear (Pre-Regulation(1929-1953))
Linear (Post-Regulation (1954-2014))
Discharge (cfs)
0
20000
40000
60000
80000
100000
120000
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Missouri River flow regulations begin (1954)

k

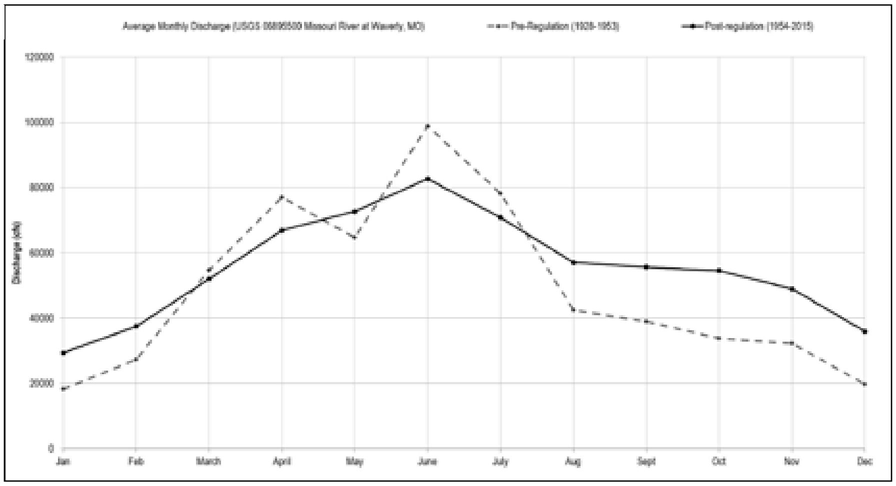

Discharge (cfs)

B5. Palmer drought severity index trends relevant to the Kansas Reach for: a) Missouri Climate Division 1; b) total precipitation trends near Lees Summit, Missouri 1950-2014 (USHCN station no. 234850); Missouri River gage data from Waverly, Missouri (USGS 06895500) for c) annual peak streamflow; d) average monthly discharges; e) average annual discharges; and f) average daily streamflow pre- (1929-1953) and post- (1954-2015) regulation periods.

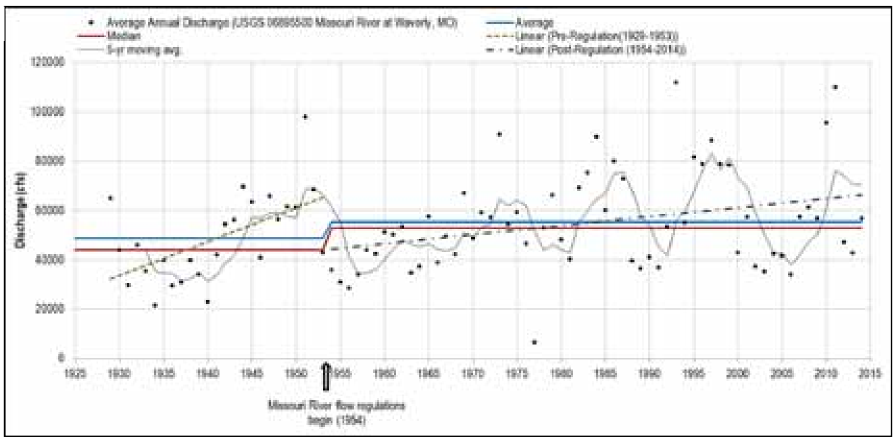


Continued next page

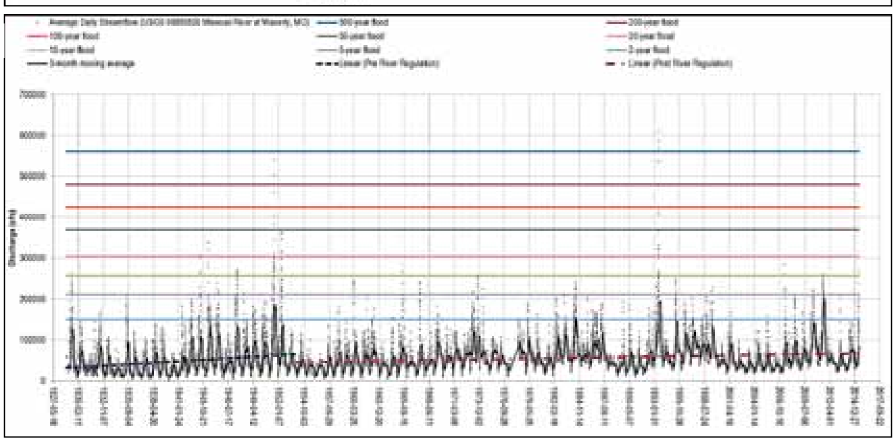
d


Average Monthly Discharge (USGS 06895500 Missouri River at Waverly, MO)
Pre-Regulation (1928-1953)
Post-regulation (1954-2015)
Discharge (cfs)
120000
100000
80000
60000
40000
20000
0
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec

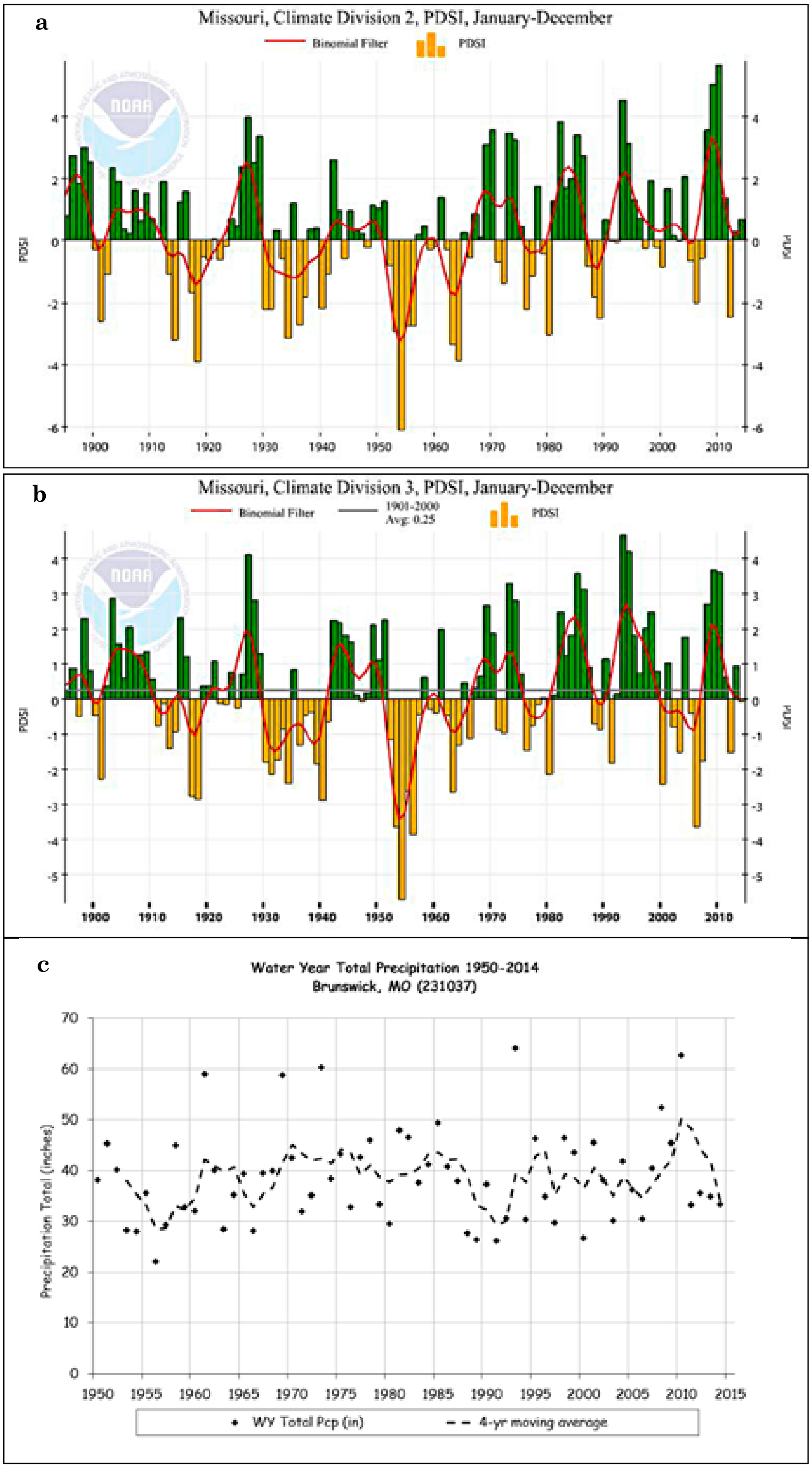
e


Average Annual Discharge (USGS 06895500 Missouri River at Waverly, MO)
Median
5-yr moving avg.
Average
Linear (Pre-Regulation(1929-1953))
Linear (Post-Regulation (1954-2014))
Discharge (cfs)
120000
100000
80000
60000
40000
20000
0
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Missouri River flow regulations begin (1954)

f


500-year flood
200-year flood
100-year flood
50-year flood
20-year flood
10-year flood
5-year flood
2-year flood
5-month moving average
Linear (Pre River Regulation)
Linear (Post River Regulation)
Discharge (cfs)
700000
600000
500000
400000
300000
200000
100000
0

B6. Palmer drought severity index trends relevant to the Grand Reach for: a) Missouri Climate Division 2 and; b) Missouri Climate Division 3; c) total precipitation trends near Brunswick, Missouri 1950-2014 (USHCN station no. 231037); and Missouri River gage data from Boonville, Missouri (USGS 06909000) for d) annual peak streamflow; e) average monthly discharges; f) average annual discharges, and; g) average daily streamflow pre- (1928-1953) and post- (1954-2015) regulation periods.

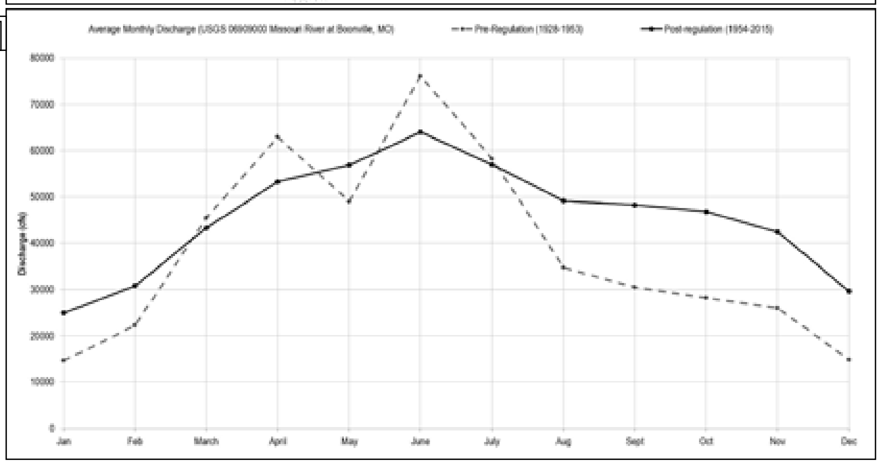


Continued next page

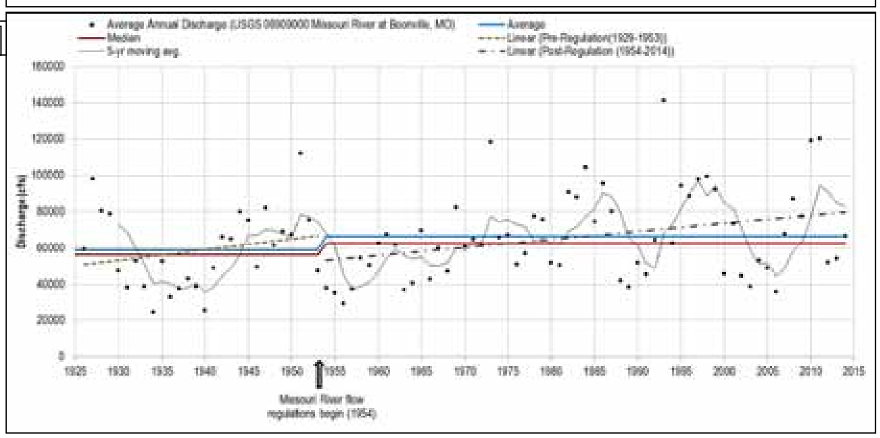
d


Peak Annual Streamflow (USGS 06909000 Missouri River at Boonville, MO)
Linear (Peak Streamflow (1926-1953))
Linear (Peak Streamflow (1954-2014))
5-yr moving avg.
Discharge (cfs)
Missouri River flow regulations begin (1954)

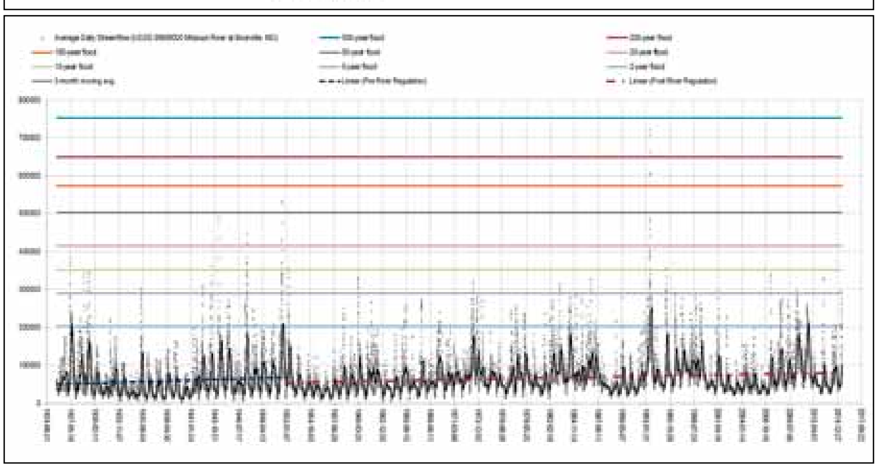
e


Average Monthly Discharge (USGS 06909000 Missouri River at Boonville, MO)
Pre-Regulation (1928-1953)
Post-regulation (1954-2015)
Discharge (cfs)
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec

f

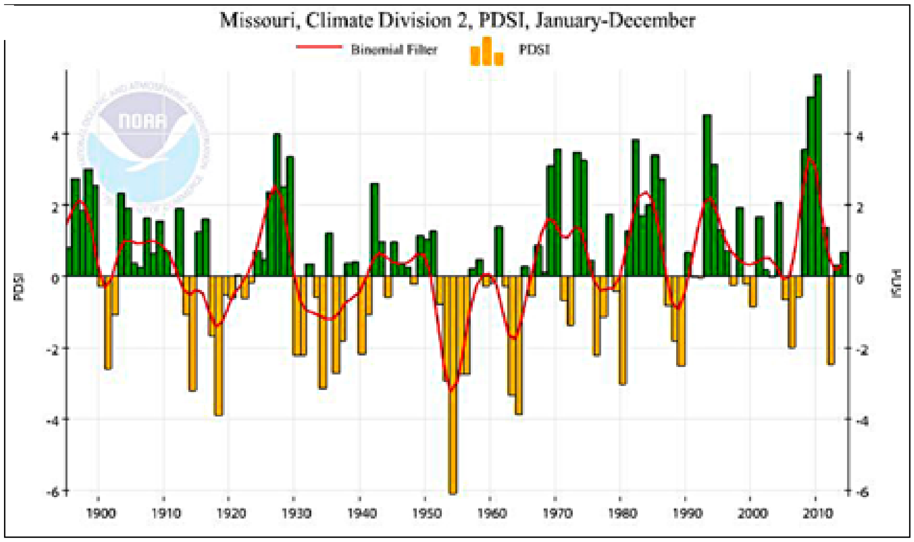

Average Annual Discharge (USGS 06909000 Missouri River at Boonville, MO)
Average
Median
Linear (Pre-Regulation(1929-1953))
5-yr moving avg.
Linear (Post-Regulation (1954-2014))
Discharge (cfs)
Missouri River flow regulations begin (1954)

g

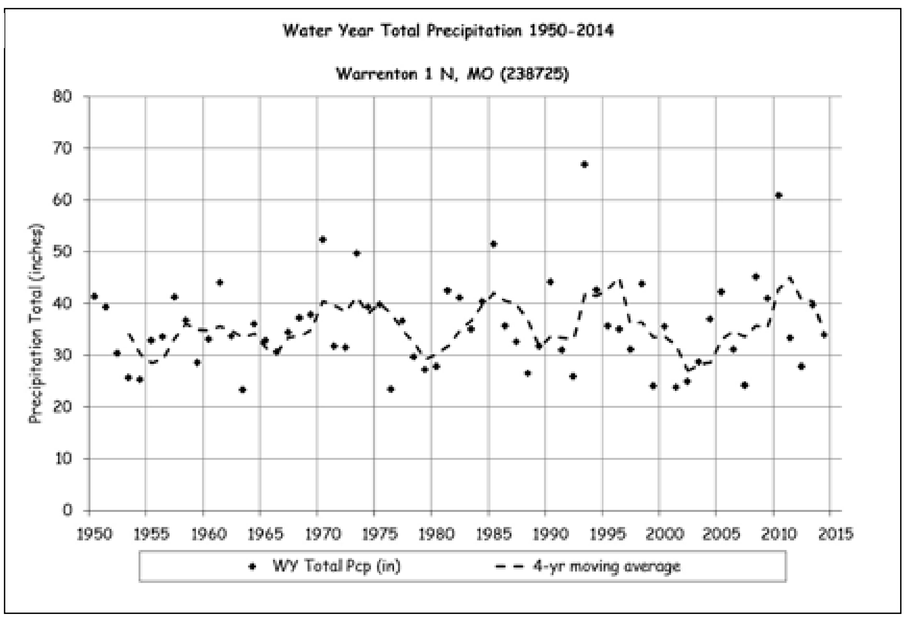


B7. Palmer drought severity index trends relevant to the Osage Reach for: a) Missouri Climate Division 2; b) total precipitation trends near Warrenton, Missouri 1950-2014 (USHCN station no. 238725); Missouri River gage data from Hermann, Missouri (USGS 06934500) for c) annual peak streamflow, d) average monthly discharges, e) average annual discharges, and f) average daily streamflow pre- (1929-1953) and post- (1954-2015) regulation periods.

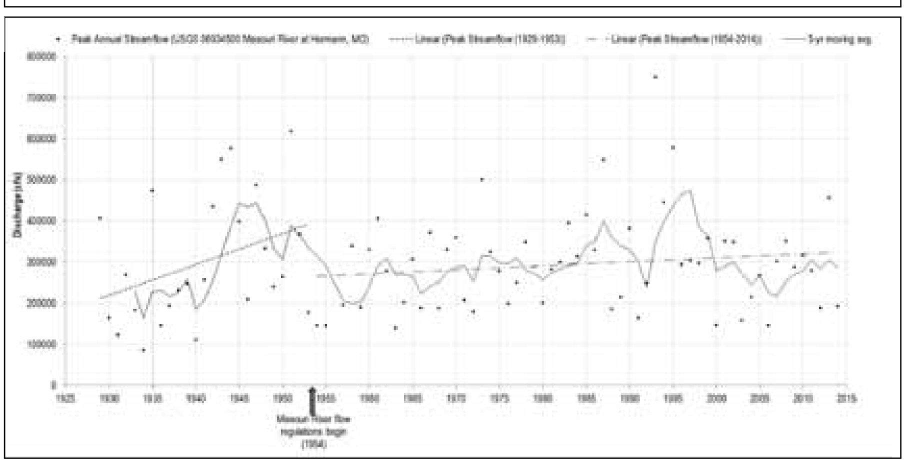
a



b



c



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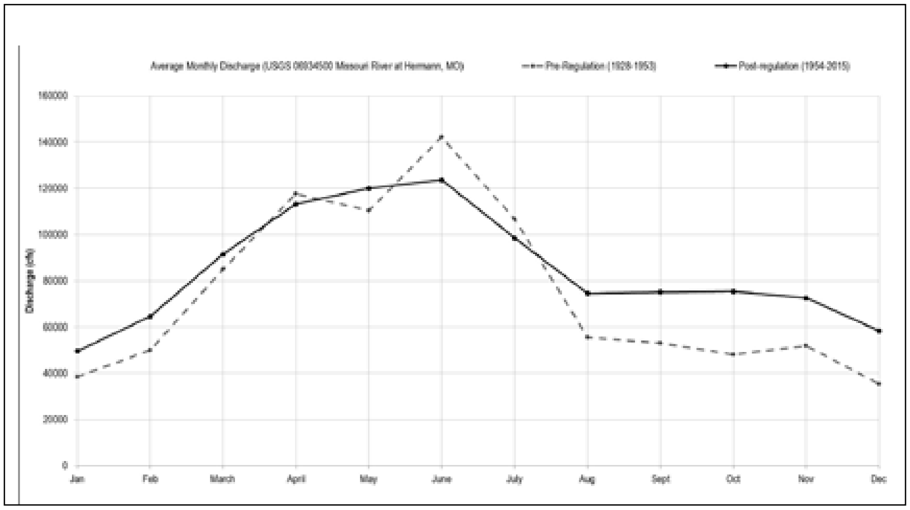
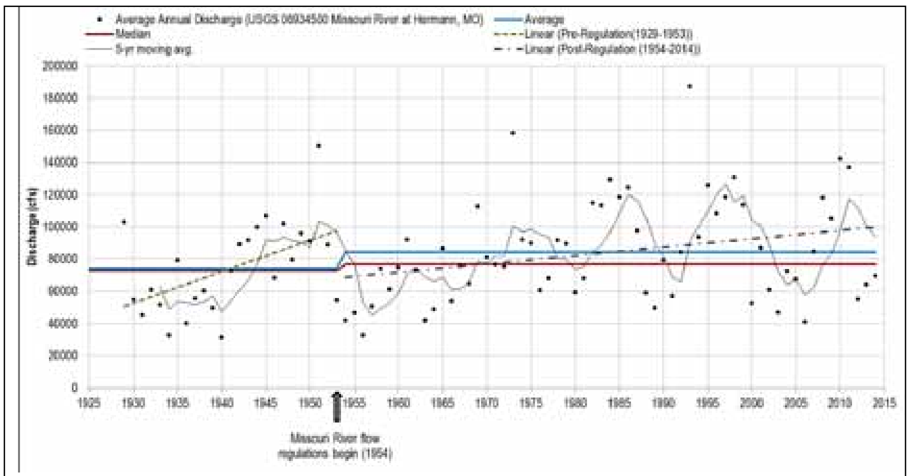
d


Average Monthly Discharge (USGS 06934500 Missouri River at Hermann, MO)
Pre-Regulation (1928-1953)
Post-regulation (1954-2015)
Discharge (cfs)
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec

e


Average Annual Discharge (USGS 06934500 Missouri River at Hermann, MO)
Median
5-yr moving avg.
Average
Linear (Pre-Regulation(1929-1953))
Linear (Post-Regulation (1954-2014))
Discharge (cfs)
Missouri River flow regulations begin (1954)

f